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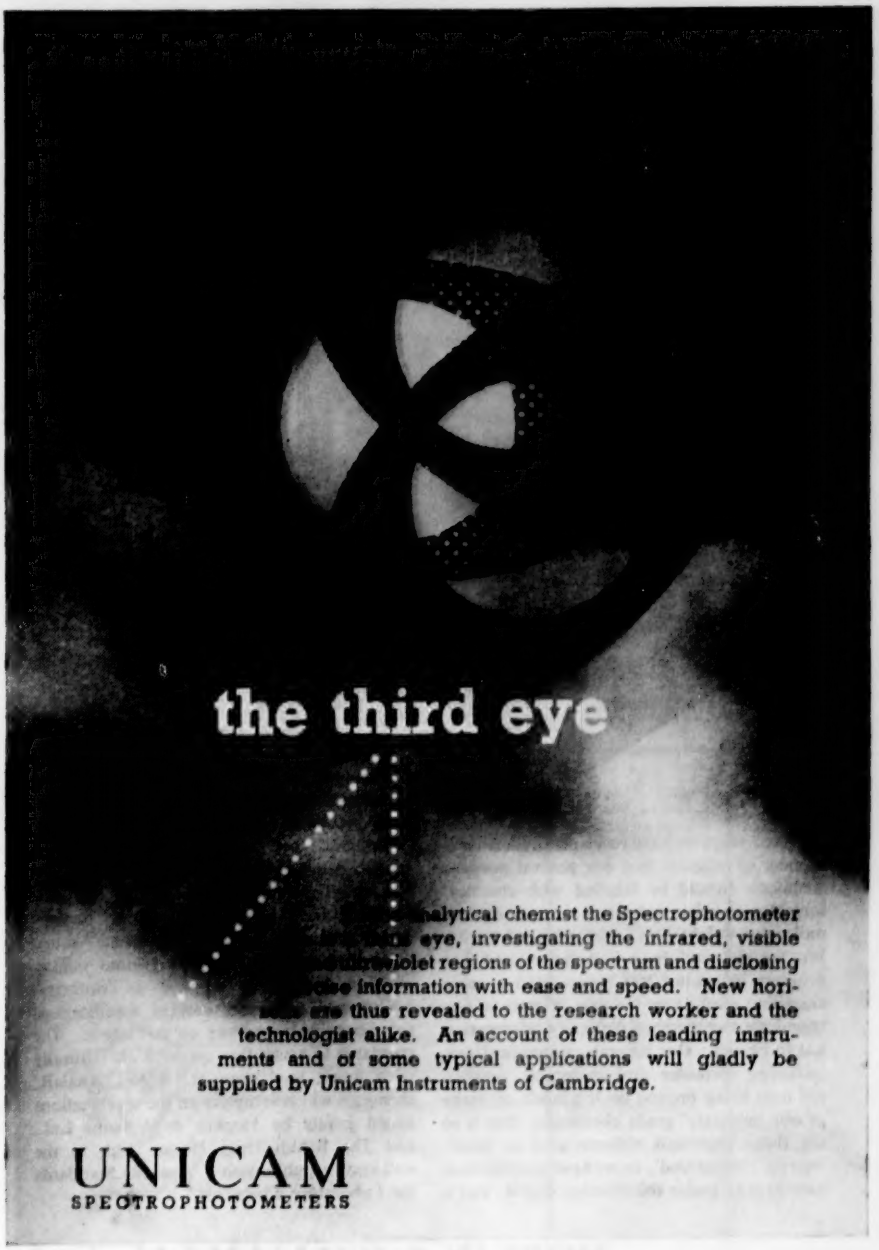
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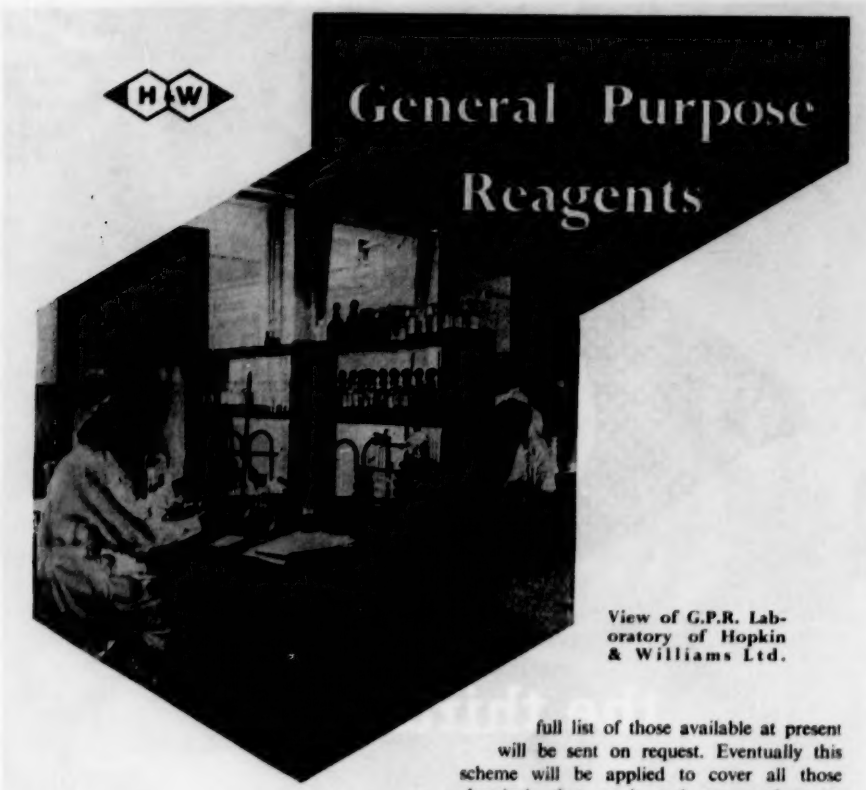

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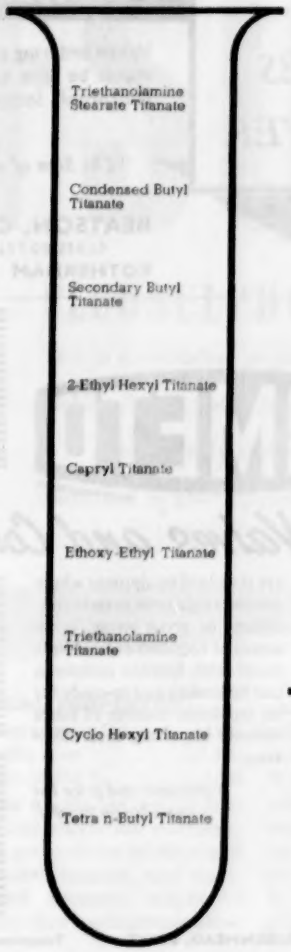

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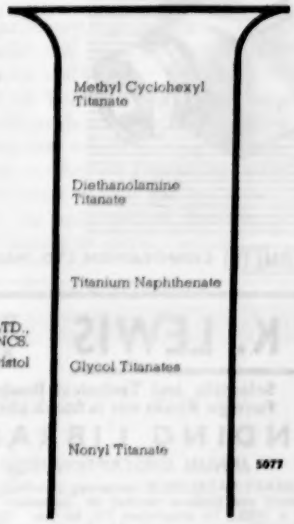

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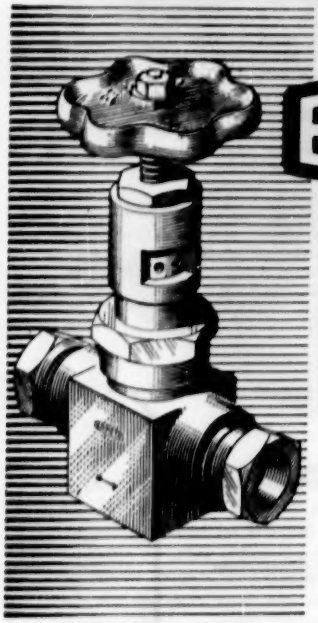

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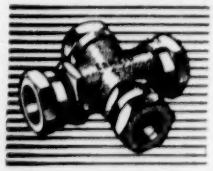

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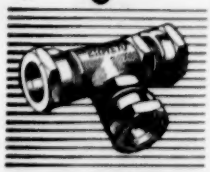

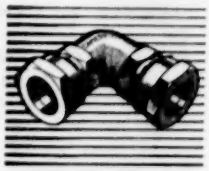

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Arsenic (As_2O_3)	no reaction
Chloride (Cl)	0·003%
Heavy Metals (Pb)	0·001%
Iron (Fe)	0·0008%
Nitrate (NO_3)	no reaction
Phosphate and Silicate (PO_4)	0·0005%
Sulphate (SO_4)	no reaction
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96. *The Conductivity of Silver Nitrate in Non-aqueous and Mixed Solvents. Part IV.**

By V. S. Griffiths and K. S. Lawrence.

The conductivity of silver nitrate solutions in ethylene glycol, in aqueous binary mixtures of ethylene glycol, and in mixtures of the glycol with pyridine and quinoline is reported and discussed.

Hydroxylic solvents have been used extensively in the study of the conductivity of electrolytes in non-aqueous and mixed solvents. Although water has received the most attention as a hydroxylic solvent the behaviour of many electrolytes in ethanol and methanol has also been investigated. Gurney [1] discusses the fact that ethylene glycol is a " suitable solvent for comparison with water, without the eccentricities of the latter," but there are relatively few data available for solutes in ethylene glycol, either alone or in binary mixtures. Muller, Raschka, and Wittman [2] studied electrolytic behaviour in this solvent and calculated values of Λ_0 for a number of salts, but it is felt that certain of their values require further investigation in the light of modern theory. Garrett and his co-workers [3, 4] reported the conductivities of thallous chloride and lead chloride over the complete range of aqueous ethylene glycol concentrations. For the former salt, they found that the dissociation constant was a minimum for solutions containing 60% of ethylene glycol and suggested that this might be due to a " solvent sorting effect " which would reduce the value of the dielectric constant in the immediate neighbourhood of the ions, facilitating the formation of triple ions. With lead chloride the discrepancies between theory and experiment were accounted for by differences between the macroscopic and so-called " microscopic " dielectric constant, the values of the latter being calculated from experimental results. However, James [5] showed that the experimental data could be satisfactorily treated without recourse to a microscopic dielectric constant, by use of the concept of ion-association and the assumption of the existence of the $PbCl^+$ ion in solutions of lead chloride, an assumption supported by spectroscopic evidence (cf. Fromherz and Kun-Hou Lih [6]). Binary mixtures of aqueous ethylene glycol were used by James [7] in an investigation of the type of forces involved in association, where it was found that in water-rich mixtures the deviations from Onsager's theory could be explained by the formation of ion-pairs being governed by purely electrostatic forces, but as the dielectric constant fell this assumption became less tenable.

In a previous paper [8a] it was shown that, for silver nitrate in acetone and binary aqueous mixtures, the dissociation constant was not entirely dependent on the dielectric constant of the solvent and it was suggested that forces other than the electrostatic attraction between the ions were involved in the association. It was thought that if the behaviour of silver nitrate in the ethylene glycol–water system was studied in a similar manner to the acetone–water system further information regarding the association–dissociation process would be obtained. Further the effect of change in the effective size of the cation would be obtained if certain organic bases, *e.g.*, pyridine and quinoline, which interact strongly with the argentous ion were added to the ethylene glycol solutions.

Results and Discussion

The conductivity of silver nitrate in ethylene glycol, and in solutions containing water, pyridine, and quinoline are given in Tables 1 and 2, all solvent compositions being given as weight percentages. The derived constants are given in Table 3.

* Part III, *J.*, 1955, 2797.

[1] Gurney, " Ionic Process in Solution," McGraw-Hill, New York, 1953, p. 187.
[2] Muller, Raschka, and Wittman, *Monatsh.*, 1927, **48**, 659.
[3] Garrett and Vellenga, *J. Amer. Chem. Soc.*, 1945, **67**, 225.
[4] Garrett and Norman, *ibid.*, 1947, **69**, 110.
[5] James, *ibid.*, 1949, **71**, 3243.
[6] Fromherz and Kun-Hou Lih, *Z. phys. Chem.*, 1931, *A*, **153**, 321.
[7] James, *J.*, 1950, 1094; 1951, 153.
[8] Griffiths and Lawrence (*a*) *J.*, 1955, 2797; (*b*) 1952, 1326.

The Λ–$\sqrt{c}$ plots for the mixtures over the concentration range studied were linear and showed only small deviations from the theoretical Onsager slope, indicating that the salt was dissociated to a very large extent. Shedlovsky's extrapolation method [9] with the tabulated extrapolation functions given by Daggett [10] was used to determine Λ_0 and K, but since the elctrolyte is almost completely dissociated the value of the latter will not

TABLE 1. *Conductivity of silver nitrate in ethylene glycol and in aqueous binary mixtures.*

Ethylene glycol		10% Water		20% Water		40% Water		60% Water		80% Water	
10^4c	Λ	10^4c	Λ	10^4c	Λ	10^4c	Λ	10^4c	Λ	10^4c	Λ
0·5445	9·05	2·0491	13·11	1·7058	18·84	1·0885	34·37	0·5056	57·47	1·1165	90·59
1·5441	8·99	2·7808	13·07	2·5004	18·71	1·6397	34·30	1·1789	57·38	2·0465	90·27
2·8938	8·93	3·6454	13·01	3·3260	18·67	2·4198	34·17	2·0158	57·15	3·2762	89·83
4·3172	8·89	4·8613	12·95	4·3788	18·59	3·2370	34·11	3·2161	57·10	4·5931	89·59
6·5899	8·84	6·3110	12·92	6·1499	18·50	4·5088	34·04	4·2185	56·95	6·2041	89·39
9·5209	8·76	7·5620	12·87	8·0632	18·47	6·6016	33·90	5·3618	56·80	7·5808	89·25
11·648	8·73	9·2355	12·83	9·4954	18·40	8·3693	33·79	7·4443	56·52	9·0771	89·06
13·941	8·67	11·146	12·79	11·618	18·32	10·774	33·64	10·178	56·34	10·770	88·82
16·416	8·63	12·572	12·77	13·432	18·30	13·632	33·55	12·548	56·25	12·147	88·62
18·932	8·59	15·560	12·72	18·526	18·16	16·236	33·44	15·084	56·12	13·303	88·52
21·919	8·55	18·680	12·67	—	—	20·191	33·31	19·312	55·86	14·886	88·37
24·427	8·51	—	—	—	—	—	—	25·813	55·62	17·381	88·17

TABLE 2. *Conductivity of silver nitrate in ethylene glycol solutions containing small additions of pyridine and quinoline.*

1% Pyridine						1·62% Quinoline					
10^4c	Λ	10^4c	Λ	10^4c	Λ	10^4c	Λ	10^4c	Λ	10^4c	Λ
0·4483	6·89	2·6788	6·77	7·6113	6·62	0·8564	6·30	4·2211	6·21	8·8638	6·13
0·8781	6·86	3·4844	6·73	9·2300	6·59	1·4123	6·27	5·3657	6·19	11·168	6·09
1·3082	6·82	4·3143	6·71	12·370	6·55	1·9586	6·25	6·1780	6·17	—	—
1·7802	6·78	6·1463	6·69	18·251	6·48	3·3541	6·23	7·4195	6·14	—	—

TABLE 3. *Ethylene glycol–water mixtures.*

Organic solvent (%)	D	Λ_0	K	$\Lambda_0\eta$	r (Å) *	a (Å)
100	37·7	9·14	0·11	1·653	2·0	4·6
90	43·7	13·27	0·18	1·838	1·8	4·0
80	49·3	19·00	0·12	1·929	1·7	2·3
60	59·4	34·62	0·24	1·627	2·0	2·1
40	66·6	57·76	0·72	1·386	2·4	2·8
20	72·8	91·17	0·28	1·258	2·6	1·3
Ethylene glycol–pyridine base mixtures.						
1% Pyridine	37·7	6·93	0·08	1·254	2·6	3·9
1·62% Quinoline ...	37·7	6·38	0·71	1·154	2·8	6·9

* r = Stokes's radius.

TABLE 4. *Walden's rule for silver nitrate in various hydroxylic solvents.*

Solvent	Ethylene glycol	Water	Methanol	Ethanol
$\Lambda_0\eta$	1·65	1·19	0·605	0·483

be very accurate. The parameter "a" was calculated by Bjerrum's theory [11] (1926, **7**, No. 9). The values for the Stokes radius "r" were obtained by assuming the mobility of the anion and cation to be equal and using Walden's rule in the form

$$\Lambda_0\eta = \frac{eF}{6\pi}\left(\frac{1}{r_+} + \frac{1}{r_-}\right)$$

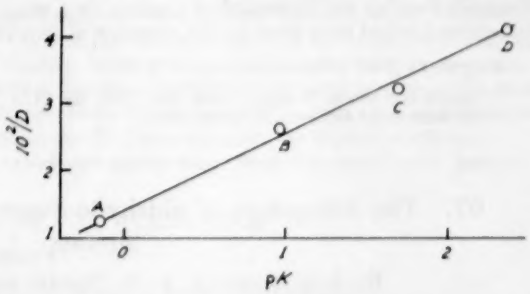
where η is the viscosity, and r_+ and r_- the apparent ionic radii ($r_+ + r_- = r$). Application of this assumption to the data for silver nitrate in water gives "r" a value of 2·7 Å, which

[9] Shedlovsky, *J. Franklin Inst.*, 1938, **225**, 739.
[10] Daggett, *J. Amer. Chem. Soc.*, 1951, **73**, 4977.
[11] Bjerrum, *Kgl. Danske Videnskab.*, 1926, **7**, No. 9.

compares favourably with the sum of the radii determined from ionic mobilities (2·68 Å) (cf. Moelwyn-Hughes [12]).

It might be expected that solutions of silver nitrate in ethylene glycol would show certain similarities to solutions in water (cf. ref. 1) if allowances could be made (*a*) for reduced mobilities of the ions owing to the high viscosity of the solvent, (*b*) for any solvation differences, and (*c*) for the greater possibility of ion association due to the lower dielectric constant of the glycol ($D = 37{\cdot}7$). In the systems studied this latter is not of cardinal importance since it has been seen that the salt is very largely dissociated even in pure ethylene glycol. As far as changes in solvation are concerned it is usually accepted that the value of the Walden product $\Lambda_0\eta$ gives an indication of such changes. Table 4 gives the value of this product for a number of hydroxylic solvents and it can be seen that the value is largest in ethylene glycol. This leads to the conclusion that the ions are less solvated in this solvent than in any of the others (see Davies [13]) and indeed it may well be that the ions possess no primary solvation in glycol.

Moelwyn-Hughes [12] showed that when ΔG^0 was plotted as a function of $1/D$ for an electrolyte in hydroxylic solvents a linear relationship existed. The figure shows a similar plot (pK–$1/D$) for silver nitrate in some hydroxylic solvents including the value for this electrolyte in ethylene glycol, and it can be seen that the collinearity is maintained.



Plot of $1/D$ *against* pK *for silver nitrate in hydroxylic solvents at 25°.*

A, Water.
B, Ethylene glycol.
C, Methanol.
D, Ethanol.

However, when such a plot was made for the ethylene glycol–water system no such simple relation held, as was also noted with the acetone–water system (Griffiths and Lawrence [8a, 8b]), the value of K being smaller than would be expected in a pure hydroxylic solvent of the same bulk dielectric constant. The reason is not clear but there are several factors which may contribute, namely, (i) a partial breakdown of the hydrogen-bonded structure of the ethylene glycol (cf. Sadek and Fuoss [14]); (ii) a change from the bulk dielectric constant of the solvent due to electrical saturation near the ion;[15] or (iii) preferential solvation leading to the formation of a region near the ion which is predominantly of one component of the binary mixture with resulting changes in dielectric constant. Yet another factor is that preferential solvation could lead to the microscopic viscosity's differing from the bulk value of the solution (see Griffiths [16]). Further, in aqueous solutions the silver ion, because of its charge and size, is an order-producing ion whilst the nitrate ion is of the disorder-producing type (Gurney, ref. 1, p. 250), but in glycol solutions both ions may be of the order-producing type. The addition of water to such electrolyte solutions will thus affect the order-producing properties of the ions which will modify such solvent interaction as may occur when the second component is added.

On considering the solutions to which small additions of pyridine and quinoline were added, it can be seen that r increases somewhat over the value holding in glycol. Although the solutions have essentially the same bulk dielectric constant, the K values are markedly

[12] Moelwyn-Hughes, "The Kinetics of Reactions in Solution," Oxford Univ. Press, 1947, 2nd Edn., p. 198.
[13] Davies, "Conductivity of Solutions," Chapman and Hall, London, 1933, 2nd Edn., pp. 117, 118.
[14] Sadek and Fuoss, *J. Amer. Chem. Soc.*, 1954, **76**, 5897.
[15] Robinson and Stokes, "Electrolytic Solutions," Butterworths, London, 1955, p. 30.
[16] Griffiths, *J.*, 1954, 686.

different, being 0·08 for solutions containing pyridine and 0·71 for those containing quinoline, and this fact is reflected in the "*a*" parameters of 3·9 Å and 6·9 Å respectively.

It is thus evident that pure ethylene glycol solutions of silver nitrate show characteristics common to the other hydroxylic solvents mentioned, in as far as the dissociation appears to be controlled by variation of the bulk dielectric constant. When binary mixtures are considered, however, no such simple relationship holds, a fact which is particularly emphasised in solutions containing organic bases, where the bulk dielectric constant remains sensibly the same but the dissociation constant alters appreciably.

Experimental

Procedure.—This is as described in Part II.[16]

Materials.—Ethylene glycol was purified by Smyth and Walls's method.[17] It was distilled under reduced pressure, and the middle fraction was then shaken with anhydrous sodium sulphate and twice redistilled, the middle fraction being retained each time. All distillations were carried out in dry nitrogen. The ethylene glycol had b. p. 197°/760 mm. and its specific conductivity was 0·03—0·06 $\times$ 10^{-6} mho. It was stored under nitrogen. Other solvents and the electrolyte were purified as described previously.[16]

The authors thank The Morgan Crucible Co., Ltd., for a scholarship (to K. S. L.), the Central Research Fund of the University of London for a grant (to V. S. G.) and Imperial Chemical Industries Limited for a grant for the provision of glassware and cells.

Battersea Polytechnic, London, S.W.11. [*Received, June 9th*, 1955.]

[17] Smyth and Walls, *J. Amer. Chem. Soc.*, 1931, **53**, 2115.
[16] Griffiths and Lawrence, *J.*, 1955, 1208.

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97. *The Interaction of* aldehydo-*Sugars and Primary Aromatic Amines.*

By J. L. Barclay, A. B. Foster, and W. G. Overend.

The reaction of 2 : 3 : 4 : 5 : 6-penta-*O*-acetyl*aldehydo*-D-galactose (I) and 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy*aldehydo*-D-glucose (IV) with certain primary aromatic amines has been studied. In each case the product was not a Schiff's base but had a structure of the type R·CH(NHR′)$_2$. An attempt has been made to correlate these results with previous observations, in terms of an equilibrium reaction.

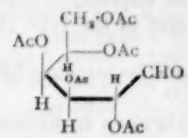
The synthesis of nucleotides in which condensation of suitable sugar derivatives with nitrogenous bases is followed by phosphorylation is well established.[1] An alternative pathway aimed at the condensation of a phosphorylated sugar derivative with a nitrogenous base is being explored in these laboratories [2] since the total synthesis of 2-deoxy-D-ribose nucleotides has not yet been achieved. We describe now some preliminary results concerning the condensation of *aldehydo*-sugar derivatives with primary aromatic amines.

The sugars studied were 2 : 3 : 4 : 5 : 6-penta-*O*-acetyl*aldehydo*-D-galactose (I) and 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy*aldehydo*-D-glucose (IV). Reaction of the former with *o*-nitroaniline in dry benzene gave only amorphous products which rapidly decomposed on exposure to air. Immediate deacetylation (sodium methoxide in methanol) of this amorphous material, followed by chromatography on alumina, afforded *N*-*o*-nitrophenyl-D-galactosylamine (characterised as the crystalline monohydrate); this was obtained in the highest yield (11·2%) by the use of ethanol as solvent and ammonium chloride as catalyst. The possibility that the galactosylamine may have originated by the condensation of D-galactose with *o*-nitroaniline following the deacetylation of unchanged *aldehydo*-sugar (I) cannot be ruled out. Under similar conditions the 2-deoxy-D-glucose derivative

[1] Baddiley, Lythgoe, McNeil, and Todd, *J.*, 1943, 383, and later papers in the same series.
[2] Cf. Barclay, Foster, and Overend, *J.*, 1955, 1541.

(IV) and *p*-toluidine did not yield a crystalline product. Clearly these experimental conditions are not satisfactory since they do not facilitate the isolation of the intermediates.

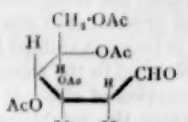
Condensation also occurred between the *aldehydo*-sugars (I or IV) and the amine hydrochloride in aqueous methanol in the presence of sodium acetate. In this manner 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy*aldehydo*-D-glucose (IV) and *p*-toluidine hydrochloride (2 mol.) yielded amorphous D-*arabo*-3 : 4 : 5 : 6-tetra-acetoxy-1 : 1-di-*p*-toluidinohexane



(I)
(= R²·CHO)

$R^1 \cdot CH(OH) \cdot OEt$
(II)

$R^1 \cdot CH(NHR^2)_2$
(III) : R^2 = 6-amino-2-methylthio-4-pyrimidyl
(V) : R^2 replaces R^1; R^2 = C_6H_4Me
(VI) : R^2 replaces R^1; R^2 = $C_{10}H_7$



(IV)
(= R²·CHO)

(V) (use of 1 mol. of the salt gave a lower yield); the 2-naphthylamine derivative (VI) was similarly obtained, the larger basic residue not impeding the reaction. However, no solid product could be isolated when *cyclo*hexylamine hydrochloride reacted with the *aldehydo*-sugar (IV) under the same conditions. 2 : 3 : 4 : 5 : 6-Penta-*O*-acetyl*aldehydo*-D-galactose (I) reacted slowly with 4 : 6-diamino-2-methylthiopyrimidine hydrochloride. However, a solution of the ethyl hemiacetal [2,3] (II) of the *aldehydo*-sugar (I) in water containing an excess of sodium acetate reacted readily with excess of this salt, to give D-*galacto*-2 : 3 : 4 : 5 : 6-penta-acetoxy-1 : 1-di-(6-amino-2-methylthio-4-pyrimidyl)hexane (III) (the use of 1 mol. of the base gave the same product in lower yield). It is apparent that the methylene group at $C_{(2)}$ in the *aldehydo*-sugar (IV) does not alter the type of reaction.

Aliphatic aldehydes (including *aldehydo*-sugars) may formally react with primary aromatic amines in four ways :

$$(1)\ R{\cdot}CHO + Ar{\cdot}NH_2 \longrightarrow R{\cdot}CH(OH){\cdot}NHAr \quad (VII)$$

e.g., the reaction of chloral with aniline; [4]

$$(2)\ R{\cdot}CHO + 2Ar{\cdot}NH_2 \longrightarrow H_2O + R{\cdot}CH(NHAr)_2 \quad (VIII)$$

e.g., the reactions described in this communication; the reaction of aniline with acetaldehyde [5] and with 2 : 4-3 : 5-di-*O*-ethylidene*aldehydo*-L-xylose; [6] related compounds of the type $R{\cdot}CH(NHAcyl)_2$ have been obtained by the treatment of acylated *aldehydo*-sugars and *O*-acyl sugars with ammonia; [7]

$$(3)\ R{\cdot}CHO + Ar{\cdot}NH_2 + R'OH\ (solvent) \longrightarrow H_2O + R{\cdot}CH(OR'){\cdot}NHAr \quad (IX)$$

e.g., the reaction of 2 : 3 : 4 : 5-tetra-*O*-acetyl*aldehydo*-D-ribose with aniline in methanol or ethanol; [8]

$$(4)\ R{\cdot}CHO + Ar{\cdot}NH_2 \longrightarrow H_2O + R{\cdot}CH{:}NAr \quad (X)$$

There is no substantiated example of the formation of a Schiff's base from an aliphatic aldehyde or *aldehydo*-sugar and a primary aromatic amine. The reaction of various *aldehydo*-sugars with 4 : 6-diamino-2-methylthiopyrimidine (which was a stage in nucleoside synthesis) was assumed to yield Schiff's bases [9] but no supporting experimental evidence was provided. Chromatographic examination (by Mr. E. B. Hancock) of the product obtained on reaction of 2 : 3 : 4-tri-*O*-acetyl-5-*O*-benzoyl*aldehydo*-D-arabinose with 4 : 6-diamino-2-methylthiopyrimidine [9a] revealed the presence of at least six components.

[3] Wolfrom, *J. Amer. Chem. Soc.*, 1930, **52**, 2464.
[4] Eibner, *Annalen*, 1898, **302**, 361.
[5] Miller and Wagner, *J. Amer. Chem. Soc.*, 1932, **54**, 3698.
[6] Bourne, Corbett, and Stacey, *J.*, 1952, 2810.
[7] Brigl, Mühlschlegel, and Schinle, *Ber.*, 1931, **64**, 2921; cf. Deulofeu and Defarrari, *J. Org. Chem.*, 1952, **17**, 1087, 1093, 1097.
[8] Overend and Parker, unpublished work.
[9] (*a*) Kenner, Lythgoe, and Todd, *J.*, 1948, 957; (*b*) Kenner, Rodda, and Todd, *J.*, 1949, 1613; Kenner, Taylor, and Todd, *J.*, 1949, 1620.

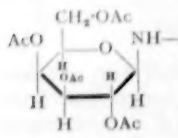
Brigl *et al.*[7] considered the product obtained from 3 : 4 : 5 : 6-tetra-*O*-benzoyl*aldehydo*-D-glucose and excess of aniline in methanol to be a true Schiff's base but the evidence they presented is not conclusive. Only syrupy products resulted on reaction of 2 : 3 : 4 : 5 : 6-penta-*O*-acetyl*aldehydo*-D-glucose with *p*-toluidine,[10] but with excess of aniline in benzene the corresponding D-galactose derivative gave a solid product which was thought to be a Schiff's base;[11] identification was complicated by the fact that, in addition to being unstable, the compound tended to crystalline with solvent. It is not improbable that this latter product and also that described by Brigl *et al.*[7] have structures of the type (VII); this is being examined further.

Related to the compounds (VII, VIII, and IX) are the hydrates and hemiacetals formed on reaction of *aldehydo*-sugars with water and alcohols respectively.[12]

Since the establishment of equilibria on dissolution of glycosylamines in hydroxylic solvents has been proved,[13] the above observations on the reaction of aliphatic aldehydes with primary aromatic amines may perhaps generally be explained on the assumption that equilibria exist in the reaction solutions involving structures of the type (VII, VIII, IX, and X). It is, perhaps, significant that examples are now known of the types (VII, VIII, and IX). A number of factors could influence the type of product obtained in a specific reaction, *e.g.*, preferential crystallization. It is interesting that under identical conditions 2 : 4-3 : 5-di-*O*-ethylidene*aldehydo*-L-xylose and aniline gave a product of the type (VIII),[6] whereas 2 : 3 : 4 : 5-tetra-*O*-acetyl*aldehydo*-D-ribose gave solely a product of the type (IX).[8]

It has been observed[6,14] in certain cases that the products obtained on the interaction of *aldehydo*-sugars with aniline showed "mutarotation" in B.P. chloroform. The small percentage of alcohol added to chloroform as a stabiliser may lead to changes in optical rotation dependent on the equilibria involving compounds of the type (VII, VIII, IX, and X). The "mutarotation" of the hemiacetals of 2 : 3 : 4 : 5 : 6-penta-*O*-acetyl*aldehydo*-D-galactose under similar conditions has been well studied.[12]

At this stage it is noteworthy that, in preliminary experiments, it was found that deacetylation of D-*galacto*-2 : 3 : 4 : 5 : 6-penta-acetoxy-1 : 1-di-(6-amino-2-methylthio-4-pyrimidyl)hexane (III) with methanolic ammonia followed by acetylation with acetic anhydride and pyridine gave a product tentatively identified as *N*-(6-acetamido-2-methylthio-4-pyrimidyl)-2 : 3 : 4 : 6-tetra-*O*-acetyl-β-D-galactosylamine (XI). It is evident that in this process a molecule of base has been eliminated, and this and related reactions are being further investigated. Thus the possibility must be considered that compounds of the type (III) are true intermediates in nucleoside synthesis involving the reaction of *aldehydo*-sugars with primary aromatic amines (cf. Kenner *et al.*[9]).



(XI)

Experimental

Starting Materials.—2 : 3 : 4 : 5 : 6-Penta-*O*-acetyl*aldehydo*-D-galactose (I) and its ethanol hemiacetal (II) were prepared according to Wolfrom's method.[12b] 3 : 4 : 5 : 6-Tetra-*O*-acetyl-2-deoxy*aldehydo*-D-glucose (IV), obtained by the action of mercuric chloride in the presence of cadmium carbonate on 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy-D-glucose diethyl thioacetal,[15] had m. p. 100°, $[\alpha]_D^{14}$ +23° (*c*, 1·5 in $CHCl_3$).

Reaction of 2 : 3 : 4 : 5 : 6-*Penta*-O-*acetyl*aldehydo-D-*galactose* (I) *with* o-*Nitroaniline.*—A suspension of the acetate (I) (0·5 g.) in dry benzene (5 ml.) was treated with excess of *o*-nitroaniline (0·35 g.) at 60° for 3 hr. Removal of the solvent under diminished pressure gave only a syrup.

[10] Kuhn and Dansi, *Ber.*, 1936, **69**, 1745.
[11] Smith, Butler, Overend, and Stacey, *Chem. and Ind.*, 1949, 551.
[12] Wolfrom, *J. Amer. Chem. Soc.*, (*a*) 1929, **51**, 2188; (*b*) 1930, **52**, 2464; (*c*) 1931, **53**, 2275; Wolfrom and Morgan, *ibid.*, 1932, **54**, 3390.
[13] Barclay, Foster, and Overend, *Chem. and Ind.*, 1953, 462; *J.*, 1955, 1541.
[14] Butler, Thesis, Birmingham.
[15] Barclay, Cleaver, Foster, and Overend, *J.*, 1956, in the press.

In a second experiment the acetate (I) (0·5 g.), *o*-nitroaniline (0·35 g.), ethanol (5 ml.), and ammonium chloride (0·05 g.) were heated under the same conditions. The syrupy residue isolated as described above was dissolved in dry methanol, and deacetylation effected by the addition of a small pellet of sodium. After 12 hr. the mixture was neutralized with solid carbon dioxide and concentrated. Material separated which decomposed on filtration. The syrupy residue remaining after evaporation of the mother-liquors was dissolved in ethanol and separated chromatographically on alumina (40 × 2 cm.). Excess of *o*-nitroaniline was eluted with ethanol and a slower-moving zone with aqueous ethanol (1 : 1; v/v). Concentration of this eluate gave a syrup which crystallized on nucleation with *N*-*o*-nitrophenyl-D-galactosylamine hydrate. After recrystallization from water the product (40 mg., 5·2%) had m. p. and mixed m. p. 182°, $[\alpha]_D^{23}$ +90° (*c*, 1·0 in pyridine) (Found: C, 45·3; H, 5·6; N, 9·0. Calc. for $C_{12}H_{16}O_7N_2,H_2O$: C, 45·3; H, 5·7; N, 8·8%).

Reaction of 3 : 4 : 5 : 6-*Tetra*-O-*acetyl*-2-*deoxy*aldehydo-D-*glucose* (IV) *with Amines.*—(a) *With* p-*toluidine and* o-*nitroaniline.* Reaction of the acetate (IV) with *p*-toluidine or *o*-nitroaniline as described yielded only tars.

(b) *With* p-*toluidine hydrochloride.* Solutions of sodium acetate trihydrate (0·45 g., 2·2 mol.) in water (2 ml.) and *p*-toluidine hydrochloride (0·43 g., 2 mol.) in water (4 ml.) were added successively to a solution of the acetate (IV) (0·5 g.) in methanol (10 ml.). After 2 hr. at 0° the yellow amorphous precipitate (0·4 g.) was collected and air-dried. Dilution of the mother-liquor with water to turbidity gave a further 0·2 g. of product. The impure solid was dissolved in the minimum volume of ethanol (containing 10% of acetic acid) at room temperature, diluted with water to turbidity, and set aside at 0°. Thereafter the solid which separated was collected and further purified by precipitation from cold ethanol by water (to turbidity). This process was repeated four times, to yield amorphous D-arabo-3 : 4 : 5 : 6-*tetra*-O-*acetoxy*-1 : 1-*di*-p-*toluidinohexane* (V) (0·39 g., 49%), sinters at 58°, m. p. 68—72°, $[\alpha]_D^{18}$ +105° (*c*, 1·43 in EtOH) (Found: C, 64·1; H, 6·8; N, 5·3. $C_{28}H_{34}O_8N_2$ requires C, 63·6; H, 6·8; N, 5·3%). The product did not reduce Fehling's solution. It was very soluble in organic solvents, and the solutions became coloured on being heated. A solution in ethanol showed ε 18,100 at 2480 Å, and 4800 at 3010 Å.

Repetition of the above experiment using equimolar quantities of reactants gave 27% of the same product.

(c) *With* 2-*naphthylamine hydrochloride.* By method (b) 2-naphthylamine hydrochloride (0·54 g., 2 mol.; m. p. 244—246°) yielded buff-coloured amorphous D-arabo-3 : 4 : 5 : 6-*tetra*-O-*acetoxy*-1 : 1-*di*-(2-*naphthylamino*)*hexane* (VI) (0·57 g., 62%), m. p. 90—94° (sinters at 88°), $[\alpha]_D^{14}$ −12·5° (*c*, 1·6 in $CHCl_3$) (Found: C, 67·8; H, 5·8; N, 4·4. $C_{34}H_{34}O_8N_2$ requires C, 68·0; H, 6·0; N, 4·7%). Its properties were similar to those of the product (V).

Reaction of 4 : 6-*Diamino*-2-*methylthiopyrimidine Dihydrochloride with* 2 : 3 : 4 : 5 : 6-*Penta*-O-*acetyl*aldehydo-D-*galactose.*—4 : 6-Diamino-2-methylthiopyrimidine,[16] m. p. 187—188°, gave a *dihydrochloride*, m. p. 210° (Found: C, 25·95; H, 4·75; N, 24·0; S, 14·3; Cl, 30·7. $C_5H_{10}N_4SCl_2$ requires C, 26·2; H, 4·4; N, 24·4; S, 14·0; Cl, 31·0%). Solutions of sodium acetate trihydrate (4·7 g., 5 mol.) in water (5 ml.) and pyrimidine dihydrochloride (3·15 g., 2 mol.) in water (5 ml.) were added successively to a solution of 2 : 3 : 4 : 5 : 6-penta-*O*-acetyl-*aldehydo*-D-galactose ethyl hemiacetal (3 g.) in water (20 ml.), and the mixture was set aside at 35° for 48 hr. Thereafter the solution was extracted with chloroform (4 × 25 ml.), and the combined extracts were washed with water and dried ($MgSO_4$). Evaporation of the solvent under diminished pressure gave an orange syrup. It was dissolved in the minimum quantity of ethanol, partially decolorised with charcoal and diluted with water to incipient turbidity. After 24 hr. at 0° the amorphous precipitate (3 g.) was collected and dried. Extraction of the mother-liquors with chloroform and repetition of the above procedure gave a further 1 g. of product. The combined materials were purified by precipitation from concentrated ethanolic solution by water (to turbidity; chilling for 24 hr.). Repitition of this process 5 times gave D-galacto-2 : 3 : 4 : 5 : 6-*penta*-O-*acetoxy*-1 : 1-*di*-(6-*amino*-2-*methylthio*-4-*pyrimidyl*)*hexane* (III) (2·8 g., 58%) as a buff-coloured solid, m. p. 125—130° (sinters at 118—119°), $[\alpha]_D^{18}$ *ca.* −50° (*c*, 1·43 in EtOH; an exact value for α could not be obtained because of the low transparency of the solution) (Found: C, 45·9; H, 5·6; S, 8·8. $C_{26}H_{34}O_{10}N_8S_2$ requires C, 45·6; H, 5·3; S, 9·4%). The product was soluble in the common organic solvents to give highly coloured solutions, and in acetic acid from which it was precipitated by the addition of ammonia.

Repetition of the reaction with equimolar quantities gave the same product in 25% yield.

[16] Wheeler and Jamieson, *Amer. Chem. J.*, 1904, **32**, 349.

Attempts to Deacetylate the Product (III).—The use of sodium and methanol gave only syrupy products.

Dry ammonia gas was passed into a solution of the compound (III) (1·0 g.) in dry methanol (20 ml.) at 0° for 90 min. Thereafter the solution was set aside at 0° for 24 hr., and at room temperature for a further 24 hr. Evaporation of the solution, and sublimation of unidentified products left a syrup which was acetylated by acetic anhydride (5 ml.) in dry pyridine (10 ml.) at room temperature during 12 hours. The solution was worked up and the amorphous residue reprecipitated four times from ethanolic solution by the addition of water. The product, N-(6-*acetamido*-2-*methythio*-4-*pyrimidyl*)-2 : 3 : 4 : 6-*tetra*-O-*acetyl*-D-*galactosylamine* (0·3 g.), sintered at 140° and had $[\alpha]_D^{18}$ −76° (*c*, 1·0 in $CHCl_3$) (Found : C, 47·5; H, 5·6; N, 11·9; S, 6·5. $C_{21}H_{26}O_{10}N_4S$ requires C, 47·7; H, 5·3; N, 10·6; S, 6·1%).

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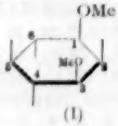
98. *Dambonitol. Part II.* Oxidation by Periodic Acid and Sodium Metaperiodate.*

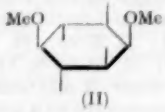
By A. K. KIANG and K. H. LOKE.

Periodic acid oxidation of dambonitol gives *meso-ribo*-β-hydroxy-αα′-dimethoxyglutaraldehyde of which some derivatives and a lactol have been obtained crystalline. Dambonitol is therefore 1 : 3-di-*O*-methyl*meso*inositol. On oxidation by sodium metaperiodate formic acid is slowly formed to a limiting value of nearly one mole per mole of dambonitol. A mechanism for the periodate oxidation is proposed.

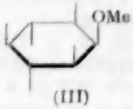
IN Part I * the isolation of dambonitol, a di-*O*-methylinositol, from the sera of the latices of *Dyera lowii* and *D. costulata* was described. As the cyclitol was optically inactive and did not form an *iso*propylidene derivative it was inferred that its structure was either (I) or (II). Further, dambonitol rapidly reacted with 2 mols. of sodium metaperiodate, producing



(I)



(II)



(III)

only 0·2—0·3 equivalent of strong acid. On the assumption that dambonitol was cleaved to two mols. of *O*-methyltartronaldehyde and that this was not readily oxidised, dambonitol was considered to be 2 : 5-di-*O*-methyl*meso*inositol (II), and the small but finite amount of strong acid was attributed to the presence of the dialdehyde in the enol form :

$$OHC{\cdot}CH(OMe){\cdot}CHO \rightleftharpoons OHC{\cdot}C(OMe){:}CH{\cdot}OH \quad (IV)$$

However, the assumption in this proof that *O*-methyltartronaldehyde would not be readily oxidised by excess of periodate was incorrect since malondialdehyde and related compounds containing active methylene groups are oxidised by periodic acid ; [1] further, by analogy with *meso*inositol [2] and sequoyitol,[3] (III), 2 : 5-di-*O*-methyl*meso*inositol (II) should consume much more than 2 mols. of periodate and more than one equivalent of formic acid should be formed. The results recorded in Part I thus actually favour structure

* Part I, Comollo and Kiang, *J.*, 1953, 3319.

[1] Huebner, Ames, and Bubl, *J. Amer. Chem. Soc.*, 1946, **68**, 1621.
[2] Fleury, Poirot, and Fieret, *Compt. rend.*, 1945, **220**, 664.
[3] Riggs, *J.*, 1949, 3199.

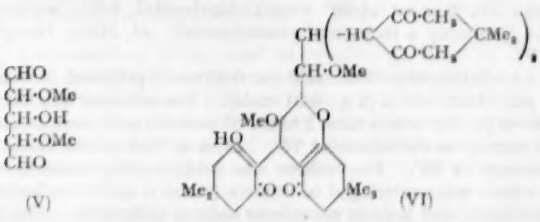
(I). We have investigated this further by working on a larger scale and isolating the oxidation product.

Dambonitol was purified until paper chromatography showed only one spot; Professor S. J. Angyal has told us that he has isolated *meso*inositol from crude dambonitol by use of a cellulose column and that careful demethylation of dambonitol gave a monomethyl-*meso*inositol, the infrared spectrum of which was identical with that of bornesitol.

The crude dialdehyde obtained by use of periodic acid [4] was a syrup. Extraction of this with absolute ethanol gave a further syrup which was strongly reducing towards Tollens's reagent and gave three crystalline dihydrazones and a crystalline dianil which behaved on analysis as derivatives of *meso-ribo*-β-hydroxy-αα′-dimethoxyglutaraldehyde (V), as expected from structure (I). When treated with dimedone in the presence of piperidine,[5] the syrup gave an anhydrobisdimedone derivative, which is stable to hot aqueous-alcoholic hydrochloric acid and is probably the pyran derivative (VI).

The syrupy dialdehyde gradually afforded crystals when kept *in vacuo* over phosphoric oxide; when recrystallised from ether, these showed on analysis the presence of three alkoxy-groups and a mol. of ethanol associated with one of the dialdehyde. The ethanol is not removed at 80° *in vacuo* over phosphoric oxide, and is thus not ethanol of crystallisation. The compound is not obtained unless ethanol is used during the working up and is probably an ethoxy-lactol (VII). Although it forms derivatives with carbonyl reagents it has no effect on Schiff's reagent.

It is thus proved that dambonitol is 1 : 3-di-*O*-methyl*meso*inositol (I). It remains to discuss why on oxidation with sodium metaperiodate (Part I) and direct titration with sodium hydroxide only 0·2—0·3 mol. of formic acid is detectable. The estimation of formic acid by direct titration after periodate oxidation has been shown to be reliable, *e.g.*, for glycerol and erythritol [6] and for αα′-trehalose.[7] However, the estimation of small amounts of formic acid is satisfactory only when the excess of periodate has been removed by ethylene glycol.[8] When this technique was used dambonitol gave larger but still inadequate

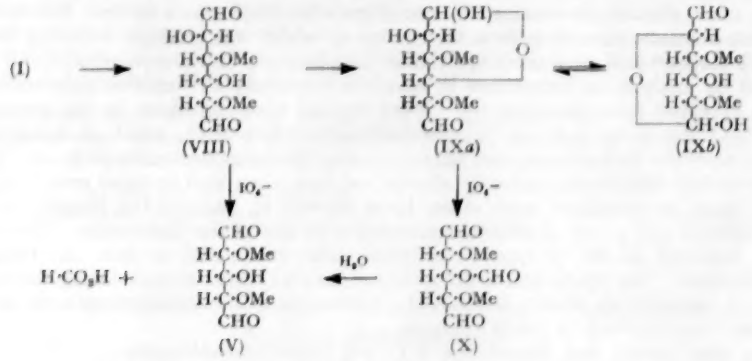


amounts of formic acid (0·3—0·5 mol.) (controls gave theoretical results). It was then noted that after 2 mols. of periodate had been consumed and the solution neutralised, acidity gradually returned until after about 280 hours a total of 1 mol. of acid was estimated. It was established that formaldehyde was not oxidised by air to formic acid, and that the dialdehyde and the lactol (VII) were also stable under the conditions used.

To account for the low yield of formic acid on oxidation of methyl cellobioside by potassium periodate Halsall, Hirst, and Jones [8] postulated that some lactol was formed and then oxidised to a formyl ester, which was only slowly hydrolysed. There is also evidence of formyl esters as intermediates in the periodate oxidation of lactose,[9] maltose,[10] and cellobiose.[11] By analogy we believe that dambonitol is first cleaved to the dialdehyde (VIII) which is partly oxidised to the 1 : 5-dialdehyde (V) and partly cyclised to the lactols (IX*a*) and/or (IX*b*). The lactol (IX*a*) is then further oxidised, yielding the formyl

[4] Cf. Jackson and Hudson, *J. Amer. Chem. Soc.*, 1937, **59**, 994.
[5] Cf. Horning and Horning, *J. Org. Chem.*, 1946, **11**, 95.
[6] Malaprade, *Bull. Soc. chim.* (*France*), 1937, **4**, 906.
[7] Jackson and Hudson, *J. Amer. Chem. Soc.*, 1939, **61**, 1530.
[8] Halsall, Hirst, and Jones, *J.*, 1947, 1427.
[9] Meyer and Rathgeb, *Helv. Chim. Acta*, 1948, **31**, 1540.
[10] Morrison, Kuyper, and Orten, *J. Amer. Chem. Soc.*, 1953, **75**, 1502.
[11] Head and Hughes, *J.*, 1954, 603.

ester (X), which is slowly hydrolysed to the 1 : 5-dialdehyde (V) and formic acid. The isomeric lactol (IX*b*) is itself stable to periodate but, being in equilibrium with (IX*a*), is removed as oxidation proceeds. Thus finally one equivalent of formic acid is formed. In conformity, heating at 70° hastened the production of titratable acid. About 90% of the total titratable acid was recovered by steam-distillation.[12]



Experimental

Microanalyses are by Dr. W. Zimmermann, D.S.I.R.O., Melbourne.

Paper Chromatography of Dambonitol.—Twice recrystallised samples gave a strong spot for dambonitol and two other weak spots when the descending chromatogram was developed with 5% ammonical silver nitrate.[13] The average R_F values obtained with butan-1-ol–ethanol–water (4 : 1 : 5 v/v) on Whatman No. 1 paper at 29° were : dambonitol, 0·20; *meso*inositol, 0·09; a minor component, 0·14 (probably a monomethyl*meso*inositol; cf. Hirst, Hough, and Jones;[14] Ballou and Anderson [13]).

Periodic Acid Oxidation.—To a solution of periodic acid (*ca.* 0·03 mole) prepared from barium periodate [7] $Ba_3I_2O_9$ was added pure dambonitol (2 g., 0·01 mole). The mixture was left in the dark at room temperature for 4—5 hr. (by which time 2 mols. of periodic acid were consumed), then neutralised with excess of strontium carbonate at 70°. After filtration, the solution was evaporated to dryness in a vacuum at 70°. The residue was rubbed with absolute ethanol (20, 10, 10 ml.). The ethanol extract was centrifuged to remove (mainly) strontiun iodate and formate, concentrated on a steam-bath, and kept *in vacuo* over sodium hydroxide. The residue was again extracted with a small quantity of absolute ethanol, and the solution after filtration again concentrated to a syrup (*A*) *in vacuo* over sodium hydroxide.

The syrup (*A*) was kept *in vacuo* over phosphoric oxide until crystals began to appear, then extracted with hot absolute ether. Concentration of the solution gave crystals (0·3 g.) on cooling in ice-water. Repeated recrystallisation in the same way gave the *lactol*, m. p. 108—109°, readily soluble in water, ethanol, and benzene, but not in light petroleum, reducing Tollens's reagent but not Schiff's reagent (Found : C, 48·95, 48·45, 48·8, 48·1; H, 8·4, 8·1, 8·2, 7·8; OAlk, as OMe, 39·75, 39·85. $C_9H_{16}O_6$ requires C, 48·65; H, 8·15; 3OMe, 41·9%).

The syrup (*A*) dialdehyde (0·5 g.) was warmed with phenylhydrazine (1 ml.) and acetic acid (2 drops) in a little ethanol for about 10 min. Water was added to turbidity. On cooling, an oil separated out which solidified under ethanol. Repeated recrystallisation from aqueous ethanol gave the yellow *bisphenylhydrazone*, m. p. 139—140° (Found : C, 63·8; H, 6·75; N, 15·35, 15·0; OMe, 17·15. $C_{19}H_{24}O_3N_4$ requires C, 64·0; H, 6·8; N, 15·7; OMe, 17·35%). The same derivative was obtained from the crystalline lactol (VII).

The *bis*-p-*nitrophenylhydrazone*, similarly prepared from either material, had m. p. 212—214° (Found : C, 51·3; H, 5·3; N, 18·5. $C_{19}H_{22}O_7N_6$ requires C, 51·1; H, 5·0; N, 18·8%).

The orange-red *bis*-2 : 4-*dinitrophenylhydrazone*, prepared in absolute ethanol containing

[12] Cf. Markham, *Biochem. J.*, 1942, **36**, 790.
[13] Ballou and Anderson, *J. Amer. Chem. Soc.*, 1953, **75**, 648.
[14] Hirst, Hough, and Jones, *J.*, 1949, 928.

a little concentrated hydrochloric acid and crystallised from ethanol–ethyl acetate, had m. p. 205—206° (Found : C, 42·55; H, 3·9. $C_{19}H_{20}O_{11}N_8$ requires C, 42·55; H, 3·75%).

The syrup (*A*) (0·6 g.) and *p*-nitroaniline (0·6 g.) were refluxed in hot ethanol (6 ml.) for 10 min. The solution became cloudy, and, on cooling in ice, deposited the *bis*-p-*nitroanil* which recrystallised from acetone as hydrated yellow needles, m. p. 181·5—182°. The water of recrystallisation was not removed at 100° *in vacuo* over phosphoric oxide during 36 hr. (Found: C, 52·2, 52·2; H, 5·6, 5·3; N, 12·6, 12·4. $C_{19}H_{20}O_7N_4.1H_2O$ requires C, 52·5; H, 5·1; N, 12·9%).

The syrup (*A*) (0·3 g. in 3 ml. ethanol) was heated with dimedone (0·4—0·5 g.) in the presence of 1 drop of piperidine at 100° for about 10 min. Water was then added to turbidity, and the mixture kept in a freezing mixture for about 4 hr. An oily *derivative* (VI) separated which solidified under ethanol. Recrystallisation from aqueous ethanol gave colourless needles, m. p. 221—222° (Found : C, 68·35, 68·45, 68·6; H, 7·8, 7·85, 8·1. $C_{39}H_{54}O_{18}$ requires C, 68·6; H, 8·0%).

Sodium Metaperiodate Oxidation.—(a) *Estimation of formic acid after reaction at room temperature.* Dambonitol (0·0651 g., 0·3125 millimole) was dissolved in a solution of sodium metaperiodate (1·223 millimole) in water (100 c.c.). The mixture was kept in the dark and aliquot portions (5 c.c.) were withdrawn at intervals. The amounts of periodate were determined as in Part I. The amounts of formic acid simultaneously liberated were determined by titration with 0·0098N-sodium hydroxide (methyl-red), 15—20 min. after pure ethylene glycol (*ca.* 1 c.c.) had been added. Each solution after neutralisation was kept in a stoppered flask and was periodically neutralised again until the solution remained yellow after 2 days. In a simultaneous blank determination with the same quantities of periodate, ethylene glycol, and methyl-red the total alkali uptake was negligible (0·04 c.c.). Typical results are tabulated.

Time (hr.)	4	19	24	44	68	92	116
Aliquot no.	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
IO_4^- uptake (mol.)	2·00	1·97	2·02	2·03	2·05	2·08	2·10
$H{\cdot}CO_2H$ (mol.)	0·21	0·26	0·20	0·22	0·29	0·29	0·31
After storage for x hr. (x =)	280	265	260	240	216	193	168
total $H{\cdot}CO_2H$ (mol.)	0·924	0·96	0·93	0·88	0·968	0·92	0·96

(b) *Estimation of formic acid on reaction at 70°.* In similar work (0·1832 millimole of dambonitol, 0·4902 millimole of metaperiodate), samples (5 c.c.) were kept for 4—10 hr. at room temperature, then treated with ethylene glycol and alkali (to neutrality), and heated at 70°. The production of acid was followed as before, the total uptake of alkali corresponding in these cases to 0·96, 0·96, 0·97 mol. of formic acid after about 2 hr. Solutions of the same quantities of periodate, ethylene glycol and methyl-red, even after addition of solid lactol, remained unchanged.

(c) *Recovery of formic acid.* A finally neutral solution from the previous experiment was acidified (Congo-red) by phosphoric acid and transferred with washing into an apparatus similar to Markham's [12] previously standardised with formic acid. The final volume was <10 c.c. as larger volumes give inconsistent results. The solution was steam-distilled for about 16—24 min. and the distillate titrated with standard alkali (phenol-red). A blank determination showed the correction required to be negligible. In three experiments recoveries of 96, 90, and 80% of volatile acid were obtained. That this acid was formic acid was confirmed by evaporating the slightly basified distillate to dryness and heating the residue in a 5% solution (2 c.c.) of mercuric sulphate in sulphuric acid in a stoppered vessel for 1 hr., and then redistilling the mixture : no volatile acid was then present.

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[*Received, July 18th*, 1955.]

99. *The Condensation of Acridone with Tertiary Aromatic Amines and the Ultraviolet Absorption Spectra of the Products.*

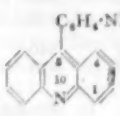
By R. M. Acheson and M. J. T. Robinson.

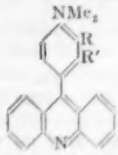
Acridone has been condensed with a number of aromatic amines, and the structures and ultraviolet absorption spectra of the products are discussed. It is suggested tentatively that the colours of 5-*p*-aminoarylacridinium ions are due to intramolecular charge-transfer phenomena.

Dimethylaniline was first condensed with acridone in the presence of phosphorus oxychloride by Ullmann,[1] who ascribed the correct structure to the product, 5-*p*-dimethylaminophenylacridine (I), proved, incidentally, by Gilman and Shirley.[2] Drozdov[3] later showed that acridone and phosphorus oxychloride may be replaced by 5-chloroacridine and aluminium chloride. This reaction has been used to prepare conveniently low-melting derivatives of acridones, but hitherto only with dimethyl- and diethyl-aniline; it has now been extended to several other substituted anilines and to naphthylamines. The general procedure used was to heat the amine with acridone and phosphorus oxychloride, or with 5-chloroacridine and aluminium chloride, in a sealed tube at 100° for between 2 hours and 2 weeks; the product was purified by chromatography.

The condensation failed with dimethyl-*p*-toluidine and dimethyl-*m*-nitroaniline, in which the *para*-position is blocked or very strongly deactivated respectively. All the other substituted anilines reacted in moderate to good yield to give products assumed to have structures (II—VIII) by analogy with the unsubstituted compound (I).

(I): R = R′ = Me
(II): R = R′ = CH_2Ph
(III): R = R′ = Ph
(IV): R = Me, R′ = NMe_2

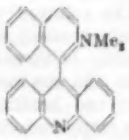




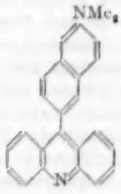
(V): R = OMe, R′ = H
(VI): R = H, R′ = Me
(VII): R = H, R′ = Br
(VIII): R = Me, R′ = H

Dimethyl-α-naphthylamine gave, in addition to a good yield of a substance assumed to be 5-(4-dimethylamino-1-naphthyl)acridine (IX), a small amount of a very high-melting base which was practically insoluble in all non-acidic solvents: analyses of the hydrochloride of the latter indicated that it might be an isomer, but the quantities available were too small for further investigation.

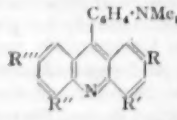
(IX)



(X)



(XI)



	R	R′	R″	R‴
(XII):	Br	H	H	H
(XIII):	Br	H	Br	H
(XIV):	Br	Br	H	Br
(XV):	Br	Br	Br	Br

Dimethyl-β-naphthylamine and acridone gave isomeric products, (X) and (XI), when aluminium chloride and phosphorus oxychloride respectively were used. These tentative structure allocations are based on the assumption that positions 1 and 6 in the naphthylamine are the most reactive and on the absorption spectra.

In glacial acetic acid or acidified ethanol most 5-*p*-aminoarylacridines give highly coloured solutions which are considered to contain acridinium monocations (*e.g.*, XVI). This is supported by the observations that the condensation products of *N*-substituted

[1] Ullmann, *Ber.*, 1907, **40**, 4796.
[2] Gilman and Shirley, *J. Amer. Chem. Soc.*, 1950, **72**, 2181.
[3] Drozdov, *J. Gen. Chem.* (*U.S.S.R.*), 1936, **6**, 219.

acridones are similarly coloured quaternary salts,[4] that the solutions give an acridinium-ion colour and fluorescence when strongly acidified unless the basicity of the amino-group is very low (as in III), and that if the basicity of the acridine nucleus is lowered by several bromine substituents the colours are not observed since, presumably, the amino-group is then relatively more basic than the acridine nucleus. Preparation of the bromoacridines (XII—XV) has been described previously.[5]

Gleu and Schubert [4] suggested that the colour is a consequence of resonance between structures (XVI) and (XVII) as in the case of the triphenylmethane dyes. Albert and Goldacre,[6] however, found no significant difference between the basicity of acridine and its 5-*p*-dimethylaminophenyl derivative (I), and concluded that the ion (XVI) was not stabilised by " additional ionic resonance " in the ground state. This is doubtless because the planar configuration required by structure (XVII) is impossible; serious interference between carbon and hydrogen atoms begins to take place in 9-phenylanthracene when the planes of the ring systems are 57° apart.[7]

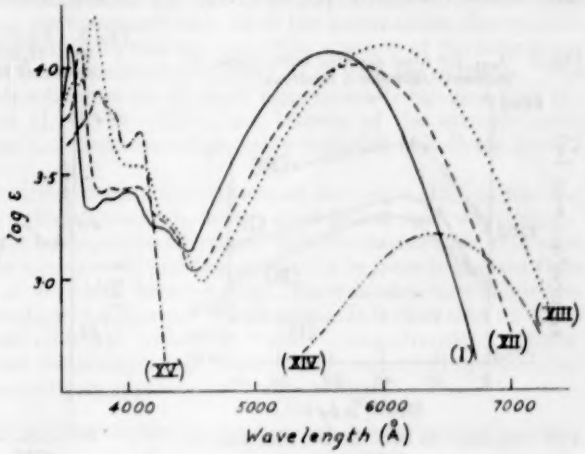
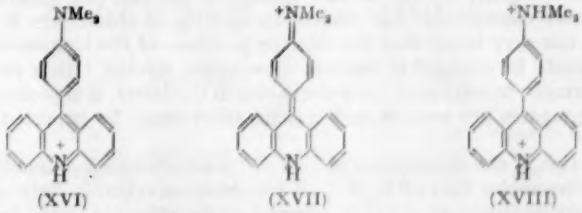


FIG. 1. *5-p-Dialkylaminoaryl-acridine monocations.*

Albert [8] suggested that there might be resonance in an excited state, but he did not amplify this. Dr. L. E. Orgel personally has pointed out that the colour is perhaps best considered as due to a charge-transfer phenomenon,[9] an electron, initially largely localised



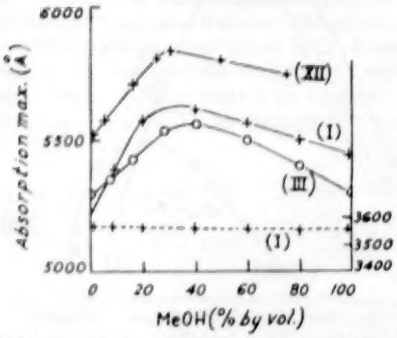
on the donor aminoaryl group, passing to the positively charged acridine ring system during light absorption. In agreement with this the ions such as (XVI) have been found to give one very broad, moderately intense band in the visible region (Fig. 1). In contrast the absorption of the dications and free bases decreases rapidly at $>$ *ca.* 4500 Å.

[4] Gleu and Schubert, *Ber.*, 1940, **73**, 757.
[5] Acheson and Robinson, *J.*, 1953, 232.
[6] Albert and Goldacre, *J.*, 1943, 454; 1946, 706.
[7] Jones, *J. Amer. Chem. Soc.*, 1945, **67**, 2127.
[8] Albert, " The Acridines," E. Arnold & Co., London, 1950, p. 133.
[9] Orgel, *Quart. Rev.*, 1954, **8**, 422.

The spectra of the acridines were measured in methanol or chloroform–methanol solutions. Sufficient mineral acid was added to develop the maximum colour as shown spectrophotometrically for the long-wavelength band for the monocations (Fig. 1, Table 2), and concentrated sulphuric acid was added until the dications were formed (Table 1). The maximum colour was observed when about three equivalents of acid had been added. It was relatively insensitive to further additions of acid, the extinction maximum only decreasing by 10% or less in the presence of 100 equivalents. At least 4% of sulphuric acid was needed to convert the compounds into their dications. Since the compounds (I—IV, XII, and XIII) give similar maximum intensities in the weakly acid solutions (Table 2), despite considerable differences in the relative basicities of the amino-group and the acridine nucleus, the formation of the monocations (cf. XVI) is probably virtually complete before the dications (cf. XVIII) are present in appreciable concentration.

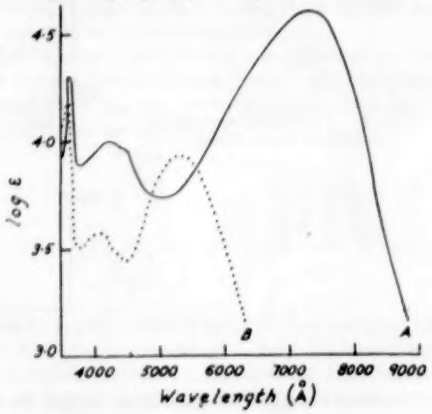
Chloroform–methanol was used for the compounds (I and XII—XV) because the last two were too sparingly soluble in methanol. The long-wavelength absorption bands of three monocations (of I, III, and XII; Fig. 2) were subject to very considerable solvent

FIG. 2. *$\lambda_{max.}$ for some acridine monocations in methanol–chloroform solutions.*



Full lines, scale on left; broken line, scale on right.

FIG. 3. *5-p-Diphenylaminophenylacridine* (III) *in* 75% H_2SO_4 (*curve A*) *and in* MeOH + 5·3 *equivs. of* H_2SO_4 (*curve B*).



effects when passing from methanol to chloroform solutions, but the 3600 Å absorption band was only affected slightly by the solvent change in the one case examined. Since the solvent effects are considerable but similar up to 60% of chloroform in the compounds examined it is not very likely that the relative positions of the long-wave maxima of the monocations would be changed in another dissociating solvent. In a poorly dissociating solvent, for example, in methanol–chloroform rich in the latter, it is probable that ion pairs and higher aggregates are present and specific effects may be expected with individual compounds.

The absorption of the monocation of 1 : 3 : 7 : 9-tetrabromo-5-*p*-dimethylaminophenylacridine (XV) resembles that of 1 : 3 : 7 : 9-tetrabromoacridine in both neutral methanol and 3% methanolic sulphuric acid; a coloured monocation could not be detected at all. It is clear that in these compounds, in contrast to the other aminoarylacridines, the steric and the electrical effect of the bromine atoms prevent the initial formation of an acridinium ion. Under the usual conditions for the qualitative observation of these colour reactions (*i.e.*, solution in acidified ethanol or acetic acid) the tribromoacridine (XIV) gave no noticeable colour because its solubility is very low, the colour intrinsically weak, and the basicity of the nucleus low; a pale green colour is observed in formic–acetic acid.

The triphenylamine derivative (III) gave a coloured monocation in several solvents and a bathochromic shift with increase in the polarity of the solvent. In concentrated sulphuric acid the absorption and fluorescence resembled those of an acridinium ion, but the dark

bluish-green solution in 75% sulphuric acid showed a very intense band at much longer wavelengths (Fig. 3). This is probably due to some irreversible change, as dilution gave first a red and then a blue solution; the original acridine is not soluble in dilute sulphuric acid of these concentrations.

The variations in the long-wavelength absorption maxima of the monocations, with 5-*p*-dimethylaminophenylacridine (I) as a standard, are such as would be expected for charge-transfer spectra. Substituents which decrease the electron-donor character of the aminoaryl group, *i.e.*, replacement of *N*-methyl by *N*-benzyl (II) or *N*-phenyl (III) or the introduction of a bromine atom into the aryl group (VII), cause considerable hypsochromic shifts. Substituents which increase the electron-donor character of the aminoaryl group, *e.g.*, methoxyl (V), or increase the acceptor properties of the acridine nucleus, *e.g.*, bromine (XII—XIV), produce bathochromic shifts. The monocation derived from the hydrazine (IV) absorbs at shorter wavelengths than the standard (I). The small effect caused by the methyl substituent in the compound (VI) is unusual when compared with the large hypso- and batho-chromic effects of hindering methyl groups in unsymmetrical and symmetrical cyanine dyes respectively [10] and the compound may be of the intermediate classification predicted by Brooker. In agreement with this the extinction maxima of the long-wavelength band is less than that of the unhindered compound (I) as with the cyanines. The dyes studied by Brooker and his colleagues are all much more intensely coloured than the monocations of the compounds (I, II, IV—XIV), and because of the extreme steric hindrance in the latter additional ionic resonance is probably negligible in both the ground and the excited state.

The absorption of the monocation of the α-naphthylamine derivative (IX), in which a benzene ring has been fused on to the standard (I), is very weak and at short wavelengths. The dimethylamino-group cannot conjugate so effectively with the naphthalene ring as it can with the benzene ring in the analogue (I) and this appears to be more important than the usual bathochromic effect of an added benzene ring. There is also more hindrance between the two ring systems and hence a decrease in intensity. It is clear that no sharp distinction can be made between ordinary " resonance " and " charge-transfer " spectra, which are two ideal extremes, but the absorption of unhindered symmetrical cyanine dyes and of the aminoarylacridines respectively approximate closely to them.

TABLE 1. *Visible and near-ultraviolet absorption maxima of some* 5-p-*aminoarylacridines.*

	Free bases			Dications			
Compound	Solvent ‡	$\lambda_{max.}$ (Å) (log ε)		Solvent ‡	$\lambda_{max.}$ (Å) (log ε)		
I	M	3580 (4·02)	4040 (3·86)	Ms	3600 (4·20)	—	4130 (3·67)
II	M	3600 (3·90)	4100 (3·87)	Ms	3600 (4·17)	—	* 4100 (3·65)
III	—	—	—	S, 98%	3600 (4·26)	—	* 4200 (3·79)
IV	M	3600 (4·02)	3950 (3·92)	Ms	3600 (4·27)	—	* 4200 (3·83)
V	M	3600 (3·99)	3850 (3·84)	Ms	3600 (4·30)	—	* 4100 (3·82)
VI	M	3600 (3·74)	—	Ms	3600 (4·29)	—	* 4100 (3·74)
VII	M	3600 (4·05)	—	Ms	3600 (4·27)	—	* 4100 (3·68)
VIII	M	3580 (3·99)	3750 (3·89)	Ms	3590 (4·16)	—	* 4150 (3·74)
IX	M	3570 (4·11)	—	Ms	3600 (4·18)	—	* 4100 (3·76)
X	C	3600 (4·25)	4200 (3·14)	Ms	3600 (4·17)	—	* 4100 (3·66)
XI	C	3600 (4·12)	—	Ms	3600 (4·16)	* 3900 (3·65)	* 4100 (3·67)
I	C–M	3580 (3·93)	4050 (3·82)	C–Ms	3600 (4·23)	—	4020 (3·72)
XII	C–M	3650 (3·90)	4150 (3·72)	C–Ms	3530 (3·85)	3680 (4·21)	4180 (3·72)
XIII	C–M	3720 (4·15)	4380 (3·79)	C–Ms	3570 (4·08)	3810 (4·37)	4170 (3·81)
XIV	C–M	3760 (4·00)	4420 (3·74)	C–Ms	† [3700 (3·97)]	3840 (4·16)	4400 (3·53)
XV	C–M	3760 (3·90)	4580 (3·72)	S, 64%	3730 (3·75)	3900 (3·83)	4580 (3·44)

* = Broad, shallow, irregular maximum. † = Shoulder.
‡ M = methanol; C = chloroform; C–M = 1 vol. chloroform diluted to 2 vols. with methanol; S = sulphuric acid; s = solution 1·5M in sulphuric acid.

Provisional structures of the two isomers obtained from *N*-dimethyl-β-naphthylamine were deduced from the spectra of their monocations. One isomer (XI) in acidified methanol gave a very broad band of low intensity at long-wavelengths, but the other (X) absorbed at only slightly longer wavelengths than the corresponding dication (Tables 1 and 2). The

[10] Brooker, White, Sprague, Dent, and van Zant, *Chem. Rev.*, 1947, **41**, 325.

data also show that the isomer (X) is even more hindered than the α-naphthylamine derivative (IX) and must therefore have the most hindered structure. The possibility that the compound (X) was 5-(*N*-methyl-β-naphthylamino)acridine, formed by demethylation and subsequent *N*-substitution, was excluded by its stability to hot dilute sulphuric acid and by the similarity of its absorption spectra to those of the isomer (XI) in neutral and strongly acid solutions.

TABLE 2. *Visible and near-ultraviolet absorption maxima of the monocations of some 5-p-aminoarylacridines.*

Compound	Solvent ‡	10^4 Molality Solute	10^4 Molality H_2SO_4	$\lambda_{max.}$ (Å) (log ε)			
I	M	0·60	1·0	—	3550 (4·09)	* 3950 (3·37)	5440 (3·94)
II	M	0·58	1·0	—	3550 (4·14)	* 4000 (3·40)	5360 (4·05)
III	M	0·57	1·5	—	3570 (4·18)	* 4000 (3·62)	5300 (3·94)
IV	M	0·81	1·0	—	3580 (4·06)	* 4000 (3·59)	5300 (3·93)
V	M	0·73	1·0	—	3600 (4·23)	—	5610 (3·40)
VI	M	0·73	1·0	—	3600 (4·11)	* 4100 (3·61)	5450 (3·17)
VII	M	0·78	1·0	—	3600 (4·21)	* 4100 (3·61)	5210 (3·51)
VIII	M	3·30	8·0	—	¶	¶	† [4500—5500] (3·49–3·27)
IX	M	0·75	2·0	—	3600 (4·23)	* 4100 (3·74)	5000—5200 (2·70)
X	M	0·50	1·0	—	¶	* 4000 (3·67)	[5200 (2·17)] †
XI	M	3·64	5·0	—	¶	* 4000 (3·65)	6200 (2·56)
I	C–M	0·49	17·5	—	3560 (4·12)	* 4000 (3·41)	5590 (4·06)
XII	C–M	0·62	26	—	3640 (4·10)	* 4100 (3·44)	5790 (4·00)
XIII	C–M	0·56	57	3580 (3·88)	3750 (4·24)	† [4100 (3·54)]	6000 (4·10)
XIV	C–M	5·01	85	—	—	—	6410 (3·20)
XV	C–M	0·90	6000	—	3780 (4·02)	4090 (3·82)	—

* † ‡ See Table 1. ¶ Not measured.

An improved synthesis of 1 : 3 : 7-tribromo-5-chloroacridine is worthy of note. Methyl *N*-phenylanthranilate gave methyl 2′ : 4′ : 4-tribromodiphenylamine-2-carboxylate when treated with a slight excess of bromine in acetic acid. Its structure was proved by hydrolysis to the acid, which was not identical with 4 : 6 : 4′-tribromodiphenylamine-2-carboxylic acid [11] but reacted with phosphorus oxychloride to give the known 1 : 3 : 7-tribromo-5-chloroacridine.[5]

EXPERIMENTAL

Acridone.—Methyl *N*-benzoyldiphenylamine-2-carboxylate (5 g.) and 100% orthophosphoric acid (10 ml.) were heated at 200—210° for 10 min., cooled to 100°, and diluted with ethanol (20 ml.), and methyl benzoate was removed in steam. The residual acridone (88—93%) was washed with dilute alkali, water, and ethanol, and recrystallised from *m*-cresol–acetic acid.

Condensations of Acridone or 5-Chloroacridine with Tertiary Aromatic Amines.—Dimethylaniline and triphenylamine were purified commercial specimens. *NN*-Dibenzylaniline, prepared from aniline, benzyl chloride, and sodium acetate, was purified by crystallisation of the hydrochloride and the free base. *m*-Bromodimethylaniline was prepared by pyrolysis of its methiodide. All the other amines were obtained by methylating primary aromatic amines with methyl sulphate and 20% aqueous sodium hydroxide at 100°; they were purified by acetic anhydride at 140° (30 min.) and then fractionally distilled. β-Dimethylaminonaphthalene was stable to light and air for months after chromatographic purification, but otherwise became purple after a few hours. *NN*-Dimethyl-*o*-toluidine had d_4^{20} 0·929$_6$ (Ley and Pfeiffer [12] give d_4^{20} 0·9287 for *NN*-dimethyl-*o*-toluidine and d_4^{20} 0·9769 for *N*-methyl-*o*-toluidine. Acridone (0·5 g.) and phosphorus oxychloride (1·0 ml.), or 5-chloroacridine (0·5 g.) and aluminium chloride (1·0 g.), were heated with the appropriate amine (2·0 g.) in a sealed tube at 100° for between 2 hours and 2 weeks. The mixtures were worked up according to Ullmann.[1] The product, in benzene, was purified chromatographically on alumina (20 g., if the amine was volatile in steam; otherwise 50—100 g.). Properties of the *products* are reported in Table 3.

2′ : 4 : 4′-Tribromodiphenylamine-2-carboxylic Acid.—Bromine (1·65 ml., 3·3 mols.) in acetic acid (15 ml.) was added to methyl diphenylamine-2-carboxylate (2·27 g.; m. p. 59—60°) in

[11] Jamison and Turner, *J.*, 1937, 1954.
[12] Ley and Pfeiffer, *Ber.*, 1921, **54**, 376.

TABLE 3. *5-p-Aminoarylacridines prepared by condensing acridone with a tertiary aromatic amine in the presence of phosphorus oxychloride.*

Compound	Heating (days)	Yield (%)	Solvent [a]	M. p.	Formula	Found (%) C	Found (%) H	Required (%) C	Required (%) H
II	½	55	B–E	164—165° [b]	$C_{33}H_{28}N_2,C_6H_6$	88·7	6·2	88·6	6·1
III	1	50	B–E	192—193	$C_{31}H_{32}N_2,EtOH$	—	—	—	—
					$C_{31}H_{32}N_2$ [c]	88·1 [d]	5·3	88·1	5·3
IV	½	50	E	178·5—180	$C_{32}H_{31}N_3$	81·1	6·5	80·7	6·5
V	½	20	E	243·5—245	$C_{32}H_{30}ON_2$	80·3	6·0	80·4	6·1
VI	2½	65	B	235—237	$C_{33}H_{30}N_2$	84·6	6·3	84·6	6·5
VII	2½	10	B–E	255—257	$C_{31}H_{17}N_2Br$	66·8 [e]	4·7	66·9	4·5
VIII	2½	70	B–E	271—273	$C_{31}H_{16}N_2$	84·6	6·3	84·5	6·1
IX	1	80	B	261—262	$C_{33}H_{30}N_2$	86·0	5·8	86·2	5·7
X [f]	2	15	B	204—206	$C_{25}H_{20}N_2$	85·9	5·7	86·2	5·7
XI	14	75	B	309—310	$C_{25}H_{20}N_2$	85·9	5·8	86·2	5·7

[a] B = benzene; E = ethanol. [b] Partial melting and resolidification at 100—110°. [c] Dried at 140° for 1 hr.; colour changes from orange to pale yellow. [d] Loss in wt. at 100° in 4 hr.: Found, 10·2; Reqd., 9·9%. [e] Found: Br, 20·9. Reqd.: Br, 21·2%. [f] Only aluminium chloride, but not phosphorus oxychloride, and 5-chloroacridine reacted with dimethyl-β-naphthylamine to give this compound.

acetic acid (10 ml.). Needles separated after 2—3 min. and the mixture was poured into water (20 ml.). The precipitate crystallised from acetone, giving the *tribromo-ester* (3·8 g., 82%) in yellow needles, m. p. 112—113° (Found: C, 36·3; H, 2·3; Br, 52·3. $C_{14}H_{10}O_2NBr_3$ requires C, 36·2; H, 2·2; Br, 51·7%). This ester was not identical (mixed m. p. depressed) with *methyl* **4 : 4′ : 6-*tribromodiphenylamine-2-carboxylate*** (prepared from the corresponding acid [11] with diazomethane in ether), which separated from methanol as yellow needles, m. p. 117—118° (Found: C, 35·7; H, 2·3%). Methyl 2′ : 4 : 4′-tribromodiphenylamine-2-carboxylate (1·0 g.), potassium hydroxide (0·5 g.), and methanol (10 ml.) were boiled for 2 hr. and the resulting solution was poured into N-hydrochloric acid (50 ml.). The precipitated *acid* (0·85 g.) crystallised from benzene–acetic acid (1 : 5) in yellow needles, m. p. 294—296° (Found: C, 35·0; H, 2·1. $C_{13}H_8O_2NBr_3$ requires C, 34·7; H, 1·8%). The acid was cyclised with phosphorus oxychloride, giving **1 : 3 : 7-tribromo-5-chloroacridine**, m. p. and mixed m. p. 232—233°.

Some of the spectral data were obtained by Mr. F. Hastings under the supervision of Dr. F. B. Strauss.

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100. *Oxidation of Organic Sulphides. Part V.* The Products of the Reaction of Organic Hydroperoxides with Alk-2-enyl Sulphides.*

By D. BARNARD.

The yields of sulphoxides from the reaction of allylically unsaturated sulphides with several organic hydroperoxides have been found to be always less than the theoretical. The dependence of the yields upon sulphide and hydroperoxide structure, the solvent used, and the reaction conditions is discussed. The non-sulphoxidic products from the reaction of 1-methylbut-1-enyl *n*-butyl sulphide with *tert.*-butyl hydroperoxide in benzene appear to arise from C–S bond cleavage and consist of di-*n*-butyl disulphide and a complex mixture of oxygenated, sulphur-free substances, including alcohols, ethers, peroxides, water, and some polymeric material. Similar products are given by other sulphides.

THE preliminary step in the ready autoxidation of unsaturated organic sulphides is considered to be formation of a hydroperoxide *via* a peroxy-radical, followed by intermolecular reaction of the hydroperoxide with a sulphide group.[1]

* Part IV, Bateman and Shipley, *J.*, 1955, 1996.

[1] Bateman and Cunneen, *J.*, 1955, 1596.

It is of obvious importance to examine analogues of the latter reaction removed from the complexities of the autoxidising system, and this has been done in the case of saturated sulphides by Bateman and Hargrave.[2] In both polar and non-polar solvents oxygen transfer occurred, *via* a cyclic transition complex, to give quantitative yields of sulphoxides over a wide range of experimental conditions according to the stoicheiometric equation :

$$RO{\cdot}OH + R'SR'' = ROH + R'{\cdot}SO{\cdot}R'' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

That this equation holds for a wide variety of hydroperoxide structures is demonstrated by the use made of the reaction to estimate hydroperoxide yields from autoxidised olefins,[3] the values obtained being in close agreement with those given by a standard procedure.[4]

The autoxidation of sulphides is generally restricted to unsaturated structures, and the present work is therefore concerned with a preliminary survey of the reaction of hydroperoxides with allylic, acyclic sulphides, mainly with a view to examining the validity of equation (1) with respect to yields of sulphoxide.

The sulphoxide yields quoted below are the mean values of, at the least, duplicate experiments and are given as the percentage of the theoretical value based on equation (1). The reproducibility was, unless otherwise stated, excellent (generally within $\pm 1\%$).

TABLE 1. *Sulphoxide yields in methanol as solvent after* 100 *hours at* 50° ± 0·1° *with* Bu^tO_2H.

	Yield (%)		Yield (%)
Bu^s 1-methylprop-2-enyl	98·8	Allyl phenyl	99·4
Bu^s 2-methylprop-2-enyl	100·6	Bu^s 1-methylbut-2-enyl	11—96
But-2-enyl Bu^s	100·0	Bu^s 1-methylbut-2-enyl *	99·6
Diallyl	99·0		

* With *cyclo*hexenyl hydroperoxide, not Bu^sO_2H.

A stoicheiometric yield of sulphoxide was obtained from the reaction with *tert.*-butyl hydroperoxide in methanol (see Table 1) with all the sulphides used except *n*-butyl 1-methylbut-2-enyl sulphide for which variations were wide and arbitrary. With *cyclo*hexenyl hydroperoxide the yield from this sulphide, and the other examples, was always stoicheiometric. This parallels the results in aprotic solvents illustrated below.

With *tert.*-butyl hydroperoxide in benzene the sulphoxide yield was in no case stoicheiometric (see Table 2), varying from 90% to 5% under the conditions chosen.

TABLE 2. *Yields from* tert.*-butyl hydroperoxide in benzene.*

Sulphide	Temp.	Reaction period (hr.)	Yield of sulphoxide (%)
Diallyl	55°	100	20
Allyl Ph	,,	,,	38
Bu^s cinnamyl	,,	,,	93
Dibenzyl	,,	,,	90
But-2-enyl Bu^s	50	,,	55
Bu^s 2-methylprop-2-enyl	,,	,,	72
,, ,,	55	,,	58
,, ,,	50	200	71
Bu^s 1-methylprop-2-enyl	50	100	18
*cyclo*Hexenyl Me	55	,,	41
,, ,,	,,	200	41
Bu^s 1-methylbut-2-enyl	50	100	5
,, ,,	,,	,,	5 *
,, ,,	,,	190	8 †
1-Methylbut-2-enyl Ph	,,	100	8
1-Methylbut-2-enyl Me	,,	,,	9
Bu^s 1-methylbut-2-enyl	,,	,,	62

* Sealed *in vacuo*. † Sealed in oxygen.

The yields from *n*-butyl 2-methylprop-2-enyl, but-2-enyl, 1-methylprop-2-enyl and 1-methylbut-2-enyl sulphide are 72, 55, 18, and 5% respectively, this being the same order

[2] Bateman and Hargrave, *Proc. Roy. Soc.*, 1954, *A*, **224**, 389, 399.
[3] Hargrave and Morris, *Trans. Faraday Soc.*, in the press.
[4] Barnard and Hargrave, *Analyt. Chim. Acta*, 1951, **5**, 476.

as that of enhancement of α-methylenic hydrogen activity in an allyl group undergoing similar methyl substitution.[5] This suggests at first sight that in the transition from polar to non-polar solvent a free-radical reaction, involving at some stage the α-methylenic hydrogen, becomes impressed upon the normal oxidation mechanism. However the excellent reproducibility of the sulphoxide yields is not in accord with this hypothesis since the balance between a free-radical and a molecular reaction would be expected to be more sensitively poised. Moreover the effect of free-radical inhibitors on the course of such oxidations [6] is directly opposed to the occurrence of a free-radical chain mechanism.

Also in Table 2 it can be seen that for *n*-butyl 1-methylbut-2-enyl sulphides replacement of the *n*-butyl group by methyl or phenyl groups had little effect whereas a striking increase in the sulphoxide yield resulted when the *tert.*-butyl group was introduced. Similar inexplicable and anomalous effects of the *tert.*-butyl group on the autoxidation of sulphides have been noted previously.[1]

The results for *n*-butyl 2-methylprop-2-enyl sulphide at 50° and 55° show that the yield decreases with an increase of temperature. This effect has been more fully investigated over a wider range of temperature and sulphides and found to be quite general.[6]

TABLE 3. *Sulphoxide yields from the reaction of sulphides with hydroperoxides in benzene after* 100 *hours.*

Sulphide	Hydroperoxide	Temp.	Yield (%)
Bu^n 2-methylprop-2-enyl	*tert.*-Butyl	55°	58
" "	Tetralyl	"	63
" "	*cyclo*Hexenyl	"	71
Bu^n 1-methylprop-2-enyl	*tert.*-Butyl	50	18
" "	Cumyl	"	16
" "	Tetralyl	"	15
" "	*cyclo*Hexyl	"	18
" "	*cyclo*Hexenyl	"	88
Bu^n 1-methylbut-2-enyl	*tert.*-Butyl	"	5
" "	Cumyl	"	14
" "	Tetralyl	"	13
" "	*cyclo*Hexyl	"	13
" "	*cyclo*Hexenyl	"	98
*cyclo*Hexenyl Me	*tert.*-Butyl	55	41
"	Cumyl	"	79
"	Tetralyl	"	74
"	*cyclo*Hexyl	"	60
"	*cyclo*Hexenyl	"	97

Table 3 shows that sulphoxide yields depend also on the hydroperoxide used, *tert.*-butyl hydroperoxide invariably giving amongst the lowest yields and *cyclo*hexenyl hydroperoxide the highest from any given sulphide. The difference in the kinetic behaviour of *tert.*-butyl and *cyclo*hexenyl hydroperoxides in their reactions with saturated sulphides in benzene has been ascribed by Bateman and Hargrave [2] largely to two reasons, the relatively large difference in acid strength, and the ability of *tert.*-butyl hydroperoxide alone to form a solvent complex. In the present instance acid strengths do not appear to be a dominating factor since, although *tert.*-butyl hydroperoxide is the weakest acid of the series, tetralyl and not *cyclo*hexenyl hydroperoxide is the strongest.[7] It might be argued that a solvent–hydroperoxide complex possessing a high oxidant activity, as postulated by Bateman and Hargrave,[2] is a necessary precursor of the non-sulphoxidic products. However the formation of a complex with benzene has been observed by infrared spectroscopic methods [7] for both *tert.*-butyl and *cyclo*hexenyl hydroperoxide and any difference in behaviour between these hydroperoxides in benzene must now be thought of, if attributed at all to solvent interaction, in terms of the reactivity of the complex. Steric considerations do not seem to be of importance.

The use of an excess of *tert.*-butyl hydroperoxide (Table 4) significantly increased the

[5] Bolland, *Trans. Faraday Soc.*, 1950, **46**, 358.
[6] Hargrave, *Proc. Roy. Soc.*, in the press.
[7] Barnard, Hargrave, and Higgins, European Molecular Spectroscopy Group, Oxford, July, 1955, and forthcoming publication.

yield of sulphoxide and more hydroperoxide disappeared than could be accounted for by the sulphide originally present. This " loss " of hydroperoxide, which was approximately equal to the deficiency in the sulphoxide yield, was not due to sulphone formation since at most minute amounts of this product were detected. Moreover although diallyl sulphoxide, as a typical example, did react with *tert.*-butyl hydroperoxide in benzene to give products other than sulphone the rate of disappearance of either component was very slow under the standard reaction conditions.

TABLE 4 *Reaction of sulphides with a two-fold excess of* tert.*-butyl hydroperoxide in benzene at* 55°.

Sulphide	Reaction time (hr.)	Hydroperoxide used (% on sulphide)	Yield of sulphoxide (%)
*cyclo*Hexenyl Me	140	134	68
Bu^n 2-methylbut-2-enyl	100	114	90

Some of the observed facts can be accounted for by postulating that hydroperoxide may react with allylically unsaturated sulphides in two ways, one of which leads to sulphoxide and the other to a product, or products, which can further react rapidly with another equivalent of hydroperoxide.

$$R^1{\cdot}SO{\cdot}R^2 \xleftarrow[\text{Slow}]{(1)} R^1SR^2 \xrightarrow[\text{Slow}]{(2)} X \xrightarrow[\text{Fast}]{RO{\cdot}OH} Y$$

The balance between reactions (1) and (2) for individual sulphides and hydroperoxides wil determine the sulphoxide yield, each equivalent of sulphide participating in reaction (2) leading to loss of two equivalents of sulphoxide under normal conditions but to loss of only one when hydroperoxide is in excess. The temperature effect noted would be accounted for by the difference in activation energy between reactions (1) and (2), and the effect of solvent by the enhancement of reaction (1) in polar media (cf. Bateman and Hargrave [2]).

No further comment will be made here upon this or other possible explanations of the experimental findings since a more detailed mechanistic approach to the problem is to be presented later.[6]

As a knowledge of the composition of the non-sulphoxidic products should aid understanding of their origin, the reaction most favourable to their production, *i.e.*, that of *tert.*-butyl hydroperoxide with *n*-butyl 1-methylbut-2-enyl sulphide in benzene was more fully investigated.

The products from initially equivalent amounts (0·648 mole) of each reactant were separated by fractional distillation into water, *tert.*-butyl alcohol, a sulphur-free product A, di-*n*-butyl disulphide and a small amount of high-boiling material with high sulphur and oxygen contents. Minute amounts of hydrogen sulphide and volatile thiols were also detected. The oxygen, sulphur, and carbon balances were complete at this stage, so loss of volatile material was negligible. Only 68% of *tert.*-butyl alcohol was found, so *tert.*-butoxy-groups had been incorporated into the other products.

Product A was a complex mixture, not resolved by fractional distillation. It was divided into six arbitrary fractions of which fractions 4 and 6 (50% of the material) occurred at ill-defined boiling-point plateaux. All had a large oxygen content (13·6% in fraction 1 rising to a maximum of 20% in fraction 4) and infrared spectroscopy revealed hydroxyl (in fractions 1 and 2 only), carbonyl (minute amounts in all fractions) and C–O bands (strong in all fractions). Acetals and ketals were absent, for carbonyl compounds were not obtained on acid hydrolysis, and epoxide analyses, by Ross's method,[8] were negative. No fraction liberated iodine from potassium iodide in acetic acid, but all, more particularly fractions 3—6, liberated iodine when shaken with constant-boiling hydriodic acid at room temperature or, more rapidly, at 80°. Quantitative estimation of this peroxidic oxygen gave variable results owing apparently to addition of the free iodine to ethylenic double bonds, but an average value of 15% peroxidic oxygen was obtained for

[8] Ross, *J.*, 1950, 2257.

fraction 4 and 6% for fraction 6. Determinations of total unsaturation by quantitative ozonolysis essentially according to Boer and Kooyman's method [9] agreed with the values found for *trans*-CH=CH– groups by infrared spectroscopy and, coupled with molecular-weight determinations, indicated that approximately one ethylenic double bond per molecule was present in fraction 4 and two per molecule in fraction 6. As most of the *n*-butyl groups originally present are accounted for as disulphide (cf. above), it can be tentatively assumed that some of the components in A are 1-methylbut-2-enol (in fractions 1 and 2), *tert.*-butyl 1-methylbut-2-enyl peroxide (in fraction 4), and bis-1-methylbut-2-enyl ether and peroxide (in fraction 6). These products indicate that one of the major reactions involves breaking of the bond between the allylic substituent and the sulphur atom.

In similar reactions with *tert.*-butyl hydroperoxide 1-methylbut-2-enyl phenyl sulphide gave mainly (*a*) a product very similar to product A and (*b*) diphenyl disulphide (91%). Water was again produced. However, *n*-butyl 1-methylallyl sulphide gave no water, and only a relatively small amount of the products was in the form of the " sulphur-free " and di-*n*-butyl disulphide fractions, the major product consisting of substances of molecular weight ranging from 200 to 600 and containing both sulphur and oxygen. The infrared spectra of these fractions were too diffuse to give useful information beyond presence of hydroxyl groups and loss of unsaturation. The product from allyl phenyl sulphide consisted entirely of similar high-boiling material. In the case of *n*-butyl 2-methylprop-2-enyl sulphide, sulphoxide was isolated in the yield indicated by analysis together with a small amount of di-*n*-butyl disulphide; no high-boiling material was formed.

It appears, therefore, that although carbon–sulphur bond scission occurs in most cases with the subsequent formation of disulphides, the inportance of this step varies very widely from sulphide to sulphide.

Some of the products from 1-methylbut-2-enyl phenyl sulphide and *tert.*-butyl hydroperoxide could have arisen by radical displacement reactions of *tert.*-butoxy- or *tert.*-butylperoxy-radicals with the sulphide, although, as has been already stated, it is not considered likely that free radicals play a part in the oxidation:

$$\left.\begin{array}{l} \mathrm{Me{\cdot}CH{=}CH{\cdot}CHMe{\cdot}S{\cdot}Ph} \xrightarrow{\mathrm{Bu^tO{\cdot}O{\cdot}}} \mathrm{Me{\cdot}CH{=}CH{\cdot}CHMe{\cdot}O{\cdot}OBu^t} \\ \qquad\qquad\qquad\qquad\quad \xrightarrow{\mathrm{Bu^tO{\cdot}}} \mathrm{Me{\cdot}CH{=}CH{\cdot}CHMe{\cdot}OBu^t} \end{array}\right\} + \mathrm{PhS{\cdot}} \longrightarrow \tfrac{1}{2}\mathrm{Ph_2S_2}$$

The production of *tert.*-butylperoxy-radicals without presence of *tert.*-butyl hydroperoxide was not feasible but the possibility of reaction of the sulphide with *tert.*-butoxy-radicals was explored by thermally decomposing di-*tert.*-butyl peroxide in chlorobenzene in its presence. No fission products of the type found in the oxidation were detected but by a normal cross-linking process the sulphide gave a dimer, trimer, and some higher polymers. All the initial peroxide was accounted for as unchanged material, *tert.*-butanol, and acetone.

Experimental

Materials.—Solvents were purified and dried by standard procedures and fractionally distilled before use, the middle cut only being used.

*cyclo*Hexenyl and tetralyl hydroperoxides were prepared and purified as described by Barnard and Hargrave [4] and had purities of 95% and 99% respectively.

*cyclo*Hexyl hydroperoxide was prepared by the method of Walling and Buckler.[10] This and commercial samples of *tert.*-butyl and cumyl hydroperoxide were purified by successive regenerations from their sodium salts followed by fractional distillation and were obtained with purities of 97%, 100%, and 99% respectively.

The sulphides were synthesised by standard procedures described, together with the physical constants of most of the examples, by Bateman and Cunneen.[1] *n-Butyl 2-methylprop-2-enyl sulphide* had b. p. 65·8—66·2°/14 mm. (Found: C, 66·7; H, 11·1; S, 22·2. $C_8H_{16}S$ requires C, 66·7; H, 11·1; S, 22·2%). Allyl phenyl sulphide had b. p. 97·5—98°/14 mm., n_D^{20} 1·5761

[9] Boer and Kooyman, *Analyt. Chim. Acta*, 1951, **5**, 550.
[10] Walling and Buckler, *J. Amer. Chem. Soc.*, 1953, **75**, 4372.

(Found: C, 72·1; H, 6·6; S, 21·3. Calc. for $C_9H_{10}S$: C, 72·0; H, 6·7; S, 21·2%). The sample of *cyclo*hexenyl methyl sulphide and samples of 1-methylbut-2-enyl sulphides were kindly provided by Drs. F. W. Shipley and J. I. Cunneen, respectively.

Method.—The following procedure was typical, deviations being specified in the text. The hydroperoxide (~0·45M) and the sulphide (~1·2M) dissolved in the appropriate solvent were sealed under purified nitrogen after thorough degassing *in vacuo*. To avoid possible catalysis the "Pyrex" glass vessels were cleaned with potassium permanganate in concentrated sulphuric acid, rinsed successively with water, ammonia solution, and distilled water, dried, and flamed. After being heated in a temperature-controlled water-bath for a period adequate for complete reaction the vessels were opened and the solvent was removed at low temperature *in vacuo*, the distillate being tested for active oxygen content (invariably negative). The residue was dissolved in "AnalaR" acetic acid and analysed for sulphoxide by Barnard and Hargrave's method.[11] When products were examined before the completion of the reaction, or when an excess of hydroperoxide was used, the acetic acid was replaced by *tert.*-butanol to avoid errors caused by acid-catalysed reactions of the hydroperoxide.

Reaction of n-Butyl 1-Methylbut-2-enyl Sulphide with tert.*-Butyl Hydroperoxide.*—A solution of the hydroperoxide (58·4 g.) and *n*-butyl 1-methylbut-2-enyl sulphide (102·4 g.) in benzene (500 ml.), degassed *in vacuo* and sealed under nitrogen, was kept at 50° ± 0·1° for 100 hr. The benzene, removed by fractional distillation, entrained water and *tert.*-butyl alcohol as the ternary and binary azeotropes, the former being dispersed as a fine suspension. Aliquot parts were analysed for (*a*) water by the Karl Fisher method [12] (Found: 3·01 g.) and (*b*) *tert.*-butyl alcohol by an infrared spectroscopic method involving the comparison of the strength of the absorption band at 3580 cm.$^{-1}$ with an appropriate calibration curve (Found: 32·5 g.). Water was first removed with anhydrous potassium carbonate, trial analyses indicating that this did not involve loss of *tert.*-butyl alcohol.

The residue left after removal of the solvent was fractionally distilled, to give product A (66·5 g.), b. p. 30—50°/11 mm., n_D^{20} 1·4280 (Found: C, 73·5; H, 11·3; S, 0·2%); product B (44·5 g.), b. p. 30—50°/0·01 mm., n_D^{20} 1·4910 (Found: C, 55·6; H, 9·85; S, 34·6%), and a higher-boiling fraction (b. p. 50—110°/0·01 mm., 10·6 g.) which was not further investigated.

Product A. This was further fractionated through a column of 12 theoretical plates. Six arbitrary fractions were collected over 27—53°/13 mm., of which the two largest were fraction 4 (12·2 g.), b. p. 44—46·5°/13 mm., n_D^{20} 1·4170 (Found: C, 68·7; H, 11·4%; *M*, 162), and fraction 6 (14·8 g.), b. p. 49—53°/13 mm., n_D^{20} 1·4290 (Found: C, 76·5; H, 11·5%; *M*, 152).

Determination of unsaturation. Fractions 4 and 6 were quantitatively ozonised in chloroform solution at −50° and absorbed 1·22 and 2·09 mols. of ozone respectively. Measurement of the strength of the 960 cm.$^{-1}$ band, with *trans*-but-2-enyl alcohol as standard, gave 0·9 and 1·84 *trans* $-CH=CH-$ groups per molecule respectively.

Determination of peroxidic oxygen content. The sample (0·1 g.) and constant-boiling hydriodic acid (3 ml.), freshly distilled from red phosphorus in nitrogen, were sealed *in vacuo* and heated, with shaking, at 80° for 2 hr. After dilution with water liberated iodine was titrated with 0·1N-thiosulphate solution. Tar, which contained iodine, was usually formed. The iodine titre of blanks was always less then the equivalent of 0·05 ml. of 0·1N-solution. Fraction 4 gave peroxidic oxygen 13·2, 16·5, 15·4%. Fraction 6 gave peroxidic oxygen 5·4, 6·2, 6·6% (calc. for $C_9H_{18}O_2$: 20·2%).

Product B. A sample (7 g.) was fractionally eluted from activated alumina (20 × 1 cm.) with light petroleum (b. p. 40°; 100 ml.). The residue (6·5 g.) left after removal of the solvent had b. p. 44—45°/0·01 mm., n_D^{20} 1·4942 (Found: C, 53·8; H, 10·1; S, 35·7. Calc. for $C_9H_{18}S_2$: C, 53·95; H, 10·1; S, 35·95%), and an infrared spectrum indistinguishable from that of di-*n*-butyl disulphide. A yellow band left on the alumina column was not further investigated.

Reaction of tert.*-Butyl Hydroperoxide with 1-Methylbut-2-enyl Phenyl Sulphide.*—The hydroperoxide (2·44 g.) and sulphide (5·0 g.) in benzene (25 ml.) after reaction as above gave water and *tert.*-butyl alcohol (not estimated), a product (1·6 g.), corresponding to product A, of b. p. 30—45°/14 mm., n_D^{20} 1·4230 (Found: C, 71·0; H, 11·5%; *M*, 170), and a crystalline residue (3·1 g.) which after recrystallisation from aqueous alcohol had m. p. 60·0—60·5° and mixed m. p. with diphenyl disulphide 60·3—60·8°.

Reaction of tert.*-Butyl Hydroperoxide with Allyl Phenyl Sulphide.*—No water was isolated from the reaction products of the hydroperoxide (3·43 g.) and sulphide (5·72 g.), and unchanged

[11] Barnard and Hargrave, *Analyt. Chim. Acta*, 1951, **5**, 536.
[12] Wernimont and Hopkinson, *Analyt. Chem.*, 1943, **15**, 272.

sulphide (1·5 g.), b. p. 42—43°/0·01 mm., n_D^{20} 1·5752 (Found: C, 71·8; H, 6·7; S, 21·3. Calc. for $C_9H_{16}S$: C, 72·0; H, 6·7; S, 21·3%), was the only distillable compound apart from *tert.*-butyl alcohol. The major product was a dark viscous residue (4·6 g.) which was dissolved in light petroleum (b. p. 40°) and fractionally eluted from alumina with more solvent (500 ml.). The eluate contained no diphenyl disulphide but left, on removal of the solvent, a small, crystalline, unidentified residue (0·05 g.), m. p. 161—162° (Found: C, 64·6; H, 6·1; S, 19·0%).

Reaction of tert.-*Butyl Hydroperoxide with* n-*Butyl* 1-*Methylprop*-2-*enyl Sulphide.*—The products, isolated as described above, from hydroperoxide (6·25 g.) and sulphide (10·0 g.) kept in benzene (50 ml.) *in vacuo* for 100 hr. at 50° ± 0·1° were *tert.*-butyl alcohol (4·35 g.), a sulphur-free product A (0·7 g.), b. p. 30—60°/12 mm. (Found: C, 69·85; H, 12·1%), product B (3·91 g.), b. p. 30—70°/0·01 mm. (Found: C, 56·4; H, 9·85; S, 28·0%), and a residue C (4·39 g.) (Found: C, 52·4; H, 9·3; S, 20·5%). After elution from alumina with light petroleum (b. p. 40°) product B was resolved into slightly impure di-*n*-butyl disulphide (1·95 g.), b. p. 42—44°/0·01 mm., n_D^{20} 1·4928 (Found: C, 54·3; H, 10·2; S, 35·2. Calc. for $C_{18}H_{18}S_2$: C, 53·95; H, 10·1; S, 35·95%. Purity >90%, determined spectroscopically).

Reaction of tert.-*Butyl Hydroperoxide with* n-*Butyl* 2-*Methylprop*-2-*enyl Sulphide.*—The hydroperoxide (9·05 g.) and sulphide (14·5 g.) in benzene (100 ml.) were caused to react under the usual conditions, giving *tert.*-butyl alcohol (Found: 7·58 g.; theor., 7·45 g.) and a distillate (14·4 g.), b. p. 34—66°/0·02 mm. (mainly 64—66°). The latter, analysed by Barnard and Hargrave's method,[11] had a purity of 68% as sulphoxide. Shaking with light petroleum (50 ml.; b. p. <40°), in which the sulphoxide is sparingly soluble, followed by the distillation of the insoluble material gave substantially pure (98%) *n-butyl* 2-*methylprop*-2-*enyl sulphoxide* (7·85 g.), b. p. 65—66°/0·02 mm., n_D^{20} 1·4885 (Found: C, 59·8; H, 9·9; S, 20·2. $C_8H_{16}OS$ requires C, 60·0; H, 10·0; S, 20·0%). The petroleum solution was run through a column of silica gel (25 g. 100 mesh), followed by more solvent (50 ml.), and the eluate evaporated to an oil (1·2 g.), b. p. 44—45°/0·01 mm., n_D^{20} 1·4939 (Found: C, 53·8; H, 10·0; S, 35·5. Calc. for $C_8H_{18}S_2$: C, 53·95; H, 10·1; S, 35·95%), identified as di-*n*-butyl disulphide from its physical and spectral characteristics.

Reaction of tert.-*Butoxy-radicals with* 1-*Methylbut*-2-*enyl Phenyl Sulphide.*—The sulphide (5·0 g.) and di-*tert.*-butyl peroxide (4·1 g.) in chlorobenzene (25 ml.) were degassed *in vacuo* and kept at 115° ± 0·1° under oxygen-free nitrogen for 77 hr. The red solution was diluted with benzene (65 ml.), and the benzene distilled off at atmospheric pressure, then the chlorobenzene at 35 mm. Both were analysed for acetone, *tert.*-butyl alcohol, and di-*tert.*-butyl peroxide content by infrared spectroscopy utilising the bands at 1718, 3580, and 873 cm.$^{-1}$ respectively, the benzene containing all three components and the chlorobenzene only the peroxide (Found: Acetone 0·69 g.; *tert.*-butyl alcohol 2·55 g.; di-*tert.*-butyl peroxide 0·535 g.). The residue (5·1 g.) left after the removal of the solvent contained no component volatile at up to 120°/0·01 mm. other than unchanged sulphide (0·8 g.) and could be only partially distilled in a pot-type "molecular" still at 120°/0·001 mm., to give a golden-yellow distillate (0·66 g.) (Found: C, 73·8; H, 7·0; S, 18·2%; *M*, 270) and a viscous residue [Found: C, 74·0; H, 6·9; S, 17·8; *M*, 520. $(C_{11}H_{12}S)_n$ requires C, 74·6; H, 7·35; S, 18·1%].

I thank Dr. K. R. Hargrave for helpful criticism of this work which forms part of the programme of research undertaken by this Association.

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101. *The Reaction of Magnesium Halides with αβ-Anhydro-sugars.*

By G. N. Richards, L. F. Wiggins, and W. S. Wise.

The reaction of αβ-anhydro-sugars with magnesium halides has been studied in ethereal and in aqueous solution. Derivatives of 3-deoxy-3-iodo-, 3-bromo-3-deoxy-, and 3-chloro-3-deoxy-α-D-altroside, of 2-chloro-2-deoxy-, 2-bromo-2-deoxy-, and 2-deoxy-2-iodo-α-D-altroside, and of 3-chloro-3-deoxy- and 3-deoxy-3-iodo-α-D-glucoside have been obtained by the reaction of magnesium halides with 2 : 3-anhydro-derivatives of methyl α-D-mannoside and -alloside in ether or tetrahydropyran. Magnesium chloride reacts rapidly with αβ-anhydro-sugars in aqueous solution in the presence of dilute hydrochloric acid. This reaction provides a diagnostic test for αβ-anhydro-sugars or αβ-anhydrides of sugar alcohols.

When αβ-anhydro-sugar derivatives are treated with Grignard reagents in ether or tetrahydropyran solution, the main products are halogeno-sugar compounds. Newth, Richards, and Wiggins (*J.*, 1950, 2336), and Richards and Wiggins (*J.*, 1953, 2442), however, found that when methyl 2 : 3-anhydro-4 : 6-di-*O*-methyl-α-D-alloside was treated with methylmagnesium iodide a *C*-methyl derivative was also formed. It therefore seemed probable that αβ-anhydro-sugars react with Grignard reagents through the magnesium dialkyls and magnesium halides which are formed therefrom, the first giving rise to *C*-alkyl compounds and the second to halogeno-sugars. Thus, it seemed worth while to study separately the reactions of magnesium dialkyls and magnesium halides with αβ-anhydro-sugars. The work reported in this paper is on the reaction with magnesium halides.

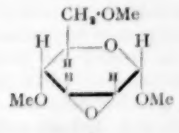
The anhydro-sugars used were the 4 : 6-*O*-benzylidene derivatives of methyl 2 : 3-anhydro-α-D-alloside and -mannoside. Newth, Richards, and Wiggins (*loc. cit.*) had found that methyl 2 : 3-anhydro-4 : 6-di-*O*-methyl-α-D-alloside (I) with a suspension of anhydrous magnesium iodide in ether gave a 45% yield of methyl 3-deoxy-3-iodo-4 : 6-di-*O*-methyl-α-D-glucoside (II) identical with the compound obtained by reaction of methylmagnesium iodide with the same anhydro-sugar. In the latter reaction, however, the 3-deoxy-3-iodo-glucoside was obtained in only 5·8% yield and other products, including a *C*-methyl sugar and a derivative of 2-deoxy-2-iodoaltroside, were also obtained.

Methyl 2 : 3-anhydro-4 : 6-*O*-benzylidene-α-D-alloside (III) behaved somewhat differently with magnesium iodide. It reacted slowly in diethyl ether but faster when the mixture was heated with an ether of higher boiling point, namely, tetrahydropyran. The product was a crystalline iodo-sugar (59% yield), identical with the methyl 4 : 6-*O*-benzylidene-2-deoxy-2-iodo-α-D-altroside (IV; R = I) previously isolated by Richards and Wiggins (*loc. cit.*) from the reaction of ethylmagnesium iodide with the same alloside (III). Similarly, when the compound (III) was treated in tetrahydropyran with anhydrous magnesium bromide or chloride, the corresponding 2-bromo-2-deoxy- (IV; R = Br) and 2-chloro-2-deoxy-altroside (IV; R = Cl) were isolated in 32% and 18% yield respectively. Reaction of magnesium chloride in tetrahydropyran at 120° in a sealed tube gave a slightly higher yield (23%) of methyl 4 : 6-*O*-benzylidene-2-chloro-2-deoxy-α-D-altroside (IV; R = Cl) but, in addition, methyl 4 : 6-*O*-benzylidene-3-chloro-3-deoxy-α-D-glucoside (V) (Newth, Overend, and Wiggins, *J.*, 1947, 10) in 3% yield. The structure (IV; R = Cl) was confirmed by hydrolysis of the compound by oxalic acid in aqueous acetone to methyl 2-chloro-2-deoxy-α-D-altroside (Newth, Overend, and Wiggins, *loc. cit.*).

The experiments with magnesium halides and the alloside (III) were repeated with a close analogue, methyl 2 : 3-anhydro-4 : 6-*O*-benzylidene-α-D-mannoside (VI). This compound also did not react with magnesium iodide in diethyl ether, but in boiling tetrahydropyran solution gave only (33%) methyl 4 : 6-*O*-benzylidene-3-deoxy-3-iodo-α-D-altroside (VII; R = I), the structure of which was established as follows: (i) Reductive dehalogenation with Raney nickel in alcohol afforded methyl 3-deoxy-α-D-mannoside (VIII), m. p. 123—124°, $[\alpha]_D^{22}$ +129·6°. Bollinger and Prins (*Helv. Chim. Acta*, 1946, **29**, 1061) described it as amorphous, showing [α] +108·9° ± 2°, the discrepancy probably

being due to the impurity of this material. (ii) When the iodide (VII; R = I) was treated with methyl iodide and silver oxide under anhydrous conditions in an attempt to prepare the 2-methyl ether it was transformed into methyl 2 : 3-anhydro-4 : 6-*O*-benzylidene-α-D-mannoside. (iii) The product (VIII) of reductive dehalogenation was not oxidised by lead tetra-acetate in acetic acid.

With magnesium bromide in tetrahydropyran, the mannoside (VI) afforded methyl 4 : 6-*O*-benzylidene-3-bromo-3-deoxy-α-D-altroside (VII; R = Br), converted by Raney nickel in alcohol into the same methyl 3-deoxy-α-D-mannoside (VIII) as was obtained from the 3-deoxy-3-iodoaltroside (VII; R = I), which proves the structure of the 3-bromide. Anhydrous magnesium chloride and the mannoside (VI) did not react in boiling tetrahydropyran and, although the starting material was consumed at 140° under pressure, the only product isolated was a chlorine-containing syrup.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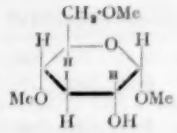
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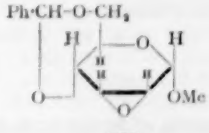
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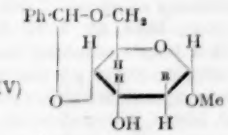
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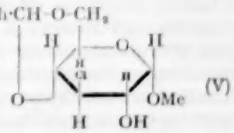
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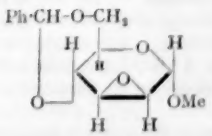
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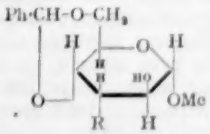
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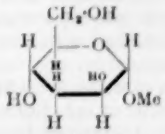
(VIII)

Thus, with both the anhydroalloside (III) and the anhydromannoside (VI) reactivity towards magnesium halides decreases in the order I > Br > Cl. It might have been expected that such salts as lithium chloride or zinc chloride would have reacted with the anhydro-sugars but in neither case could products other than original starting materials be recovered; it must be inferred that lithium and zinc chloride are less reactive than magnesium chloride towards αβ-anhydro-sugars in ether.

The relative ease of fission of the epoxide ring in anhydro-sugars by magnesium halides in ether and the known fission of ethylene oxide itself in water in the presence of high concentrations of halide ions with formation of ethylene halogenohydrins (Bronsted, Kilpatrick, and Kilpatrick, *J. Amer. Chem. Soc.*, 1929, **51**, 428) led us to examine their reaction with magnesium salts in aqueous solution.

Peat and Wiggins (*J.*, 1938, 1088) had shown that cold 5% hydrochloric acid did not open the oxide ring of methyl 2 : 3-anhydro-4 : 6-di-*O*-methyl-α-D-alloside (I) although at 95° it caused both ring fission and hydrolysis of the methyl glucoside group. However, the same anhydro-sugar derivative in cold 0·5N-hydrochloric acid saturated with magnesium chloride very rapidly gave a crystalline chlorodeoxy-4 : 6-di-*O*-methylhexoside. This was the 4 : 6-di-*O*-methyl derivative of either methyl 2-chloro-2-deoxy-α-D-altroside or 3-chloro-3-deoxy-α-D-glucoside. Hydrolysis led to the corresponding chlorodeoxy-sugar which, because it reacted with 1 mol. of sodium metaperiodate, is accorded the glucose structure. 2-Chloro-2-deoxy-4 : 6-di-*O*-methylaltrose would not have been expected to react with sodium metaperiodate.

In this reaction of αβ-anhydro-sugars with dilute hydrochloric acid saturated with

magnesium chloride, hydrogen chloride is consumed. The reaction can therefore be followed by titration with alkali. Methyl 2 : 3-anhydro-4 : 6-di-*O*-methyl-α-D-alloside when treated at room temperature with 0·5N-hydrochloric acid saturated with magnesium chloride consumes 98% of the theoretical amount of alkali in 15 min. A selection of sugar and sugar alcohol anhydrides was treated similarly, with the results shown in the accompanying Table. The reaction appears to be diagnostic for αβ-anhydro-sugars as well as offering a method of preparation of halogeno-sugars.

Anhydride	Alkali consumed in 15 min. (% theor. for 1 anhydro-ring)
Methyl 2 : 3-anhydro-4 : 6-di-*O*-methyl-α-D-alloside	98
5 : 6-Anhydro-1 : 2-*iso*propylideneglucofuranose	87 (0 *)
1 : 4-3 : 6-Dianhydro-2 : 5-di-*O*-methylsorbitol	0
1 : 6-3 : 4-Dianhydro-β-D-mannose	93
1 : 5-Anhydromannitol (styracitol)	0

* No magnesium chloride added.

Experimental

Reaction of Methyl 2 : 3-Anhydro-4 : 6-O-benzylidene-α-D-alloside with Anhydrous Magnesium Halides.—(a) *Magnesium iodide.* (i) The alloside was extracted from the thimble of a Soxhlet apparatus by boiling anhydrous ether into ether containing an excess of anhydrous magnesium iodide (cf. Nystrom and Brown, *J. Amer. Chem. Soc.*, 1947, **69**, 1197, for this method in connection with lithium aluminium hydride). After 1 hour's refluxing the starting material (96%) was recovered as described below. (ii) The alloside (0·510 g.) was heated under reflux for 2 hr. with anhydrous tetrahydropyran (20 c.c.) and magnesium iodide (1·5 g.). The solution was cooled to room temperature, and water (20 c.c.) added, followed by slight excess of dilute hydrochloric acid to dissolve the precipitated magnesium hydroxide. The tetrahydropyran solution was separated, washed with sodium hydrogen carbonate and sodium thiosulphate solutions and with water, dried (Na_2SO_4), and evaporated to dryness. The residue crystallised on inoculation and, recrystallised from ethanol, gave methyl 4 : 6-*O*-benzylidene-2-deoxy-2-iodo-α-D-altroside (0·445 g., 59%), cubes, m. p. 105—106° alone or in admixture with an authentic sample (Richards and Wiggins, *J.*, 1953, 2442).

(b) *Magnesium bromide.* The alloside (0·504 g.) and anhydrous magnesium bromide (1·4 g.) were heated under reflux for 2½ hr. with anhydrous tetrahydropyran (20 c.c.) with stirring. The mixture, treated in the usual way, yielded a yellow syrup which, on trituration with ether and light petroleum, yielded methyl 4 : 6-*O*-benzylidene-2-bromo-2-deoxy-α-D-altroside (0·34 g., 52%). When recrystallised from ethanol, this had m. p. and mixed m. p. 117·5—118·5°.

(c) *Magnesium chloride.* (i) The alloside (1·01 g.) was heated with tetrahydropyran (40 c.c.) and anhydrous magnesium chloride (0·72 g.) under reflux and stirred for 2 hr., then cooled to room temperature. Water (20 c.c.) was added. The precipitated crystalline solid (0·6 g.), when separated at the centrifuge, washed with water, and dried, had m. p. 199—200° alone or in admixture with starting material. The tetrahydropyran layer was separated, washed as in (a), dried (Na_2SO_4) and evaporated to dryness. The white crystalline residue was extracted with ethanol (30 c.c.) at room temperature and the insoluble portion separated; this was unchanged starting material (0·18 g.), m. p. 197—199°. The extract was evaporated to dryness and the residue crystallised by trituration with ether. After recrystallisation from ethyl acetate–light petroleum (b. p. 60—80°), *methyl 4 : 6-O-benzylidene-2-chloro-2-deoxy-α-D-altroside* (0·162 g., 14%) had m. p. 102—103·5°, $[\alpha]_D^{22}$ +88·4° (*c*, 1 in $CHCl_3$) (Found : C, 55·7; H, 5·5. $C_{14}H_{17}O_5Cl$ requires C, 55·9; H, 5·7%).

(ii) The alloside (1·04 g.), tetrahydropyran (30 c.c.), and anhydrous magnesium chloride (1 g.) were heated at 120° for 10 hr. in a sealed glass tube. Some insoluble amorphous brown material had then appeared. Water, followed by dilute hydrochloric acid, was added and the tetrahydropyran layer washed and dried as above. On evaporation of the solvent a brown amorphous residue remained which was dissolved in ether (4 c.c.) and light petroleum (4 c.c.; b. p. 60—80°) and chromatographed on alumina (40 × 1 cm.). Elution with ether–light petroleum (1 : 5) gave as first fraction a yellow liquid (0·348 g.) having a strong odour of benzaldehyde; it seemed probable that this material contained decomposition products formed by the prolonged heating and it was not further investigated. Elution with the same mixed solvents gave as second fraction methyl 4 : 6-*O*-benzylidene-2-chloro-2-deoxy-α-D-altroside

(0·296 g. 25·1%) which, crystallised under ether and recrystallised from ethanol, had m. p. and mixed m. p. 102—103°. A later fraction yielded 48 mg. of methyl 4 : 6-*O*-benzylidene-3-chloro-3-deoxy-α-D-glucoside which, recrystallised from ethyl acetate–light petroleum (b. p. 60—80°), had m. p. 164—165°, $[\alpha]_D^{21}$ +51·5° (*c*, 1·5 in $CHCl_3$) (Found: C, 56·0; H, 5·4. Calc. for $C_{14}H_{17}O_5Cl$: C, 55·9; H, 5·7%) (cf. Newth, Overend, and Wiggins, *loc. cit.*).

Treatment of Methyl 4 : 6-O-*Benzylidene-2-chloro-2-deoxy-α-D-altroside with Toluene-p-sulphonyl Chloride.*—The altroside (89 mg.) in dry pyridine (2 c.c.), treated with toluene-*p*-sulphonyl chloride (0·2 g.) at room temperature for 18 hr., gave the 3-*toluene*-p-*sulphonate*, m. p. 153—153·5° (from ethanol–water), $[\alpha]_D^{21}$ +43·6° (*c*, 1 in $CHCl_3$) (Found: C, 55·5; H, 5·1. $C_{21}H_{23}O_7ClS$ requires C, 55·4; H, 5·1%).

Hydrolysis of Methyl 4 : 6-O-*Benzylidene-2-chloro-2-deoxy-α-D-altroside with Oxalic Acid.*—A solution of the altroside (0·184 g.) in acetone (15 c.c.) was heated with aqueous oxalic acid (0·6 g. of the dihydrate in 2 c.c. of water), the optical rotation changing from $[\alpha]_D^{21}$ +88·7° (initial) to +77·6° (4·5 hr., const.). Then the solution was neutralised with barium carbonate and filtered and the filtrate evaporated to dryness. The residue was steam-distilled until free from benzaldehyde and again evaporated to dryness, and this residue was taken up in water. The solution was filtered and evaporated to a colourless syrup which crystallised readily on trituration with ethyl acetate. Recrystallised from the same solvent, methyl 2-chloro-2-deoxy-α-D-altroside (0·057 g., 44%) had m. p. and mixed m. p. 161—162° (Newth, Overend, and Wiggins, *loc. cit.*). By the procedure of Hockett and McClenahan (*J. Amer. Chem. Soc.*, 1939, **61**, 1667) a solution of the altroside (57·0 mg.) in glacial acetic acid (50 c.c.) consumed 1·02 mols. of lead tetra-acetate in 1 hr. at room temperature.

Reaction of Methyl 2 : 3-*Anhydro*-4 : 6-O-*benzylidene*-α-D-*mannoside with Anhydrous Magnesium Halides.*—(a) *Magnesium iodide.* The anhydromannoside (0·519 g.), anhydrous magnesium iodide (1·5 g.), and tetrahydropyan (20 c.c.) were heated under reflux for 3 hr., then cooled and water (20 c.c.) was added. The solution was then acidified, and the ethereal layer separated, washed in the usual way, dried (Na_2SO_4), and evaporated. Fractional recrystallisation of the residue from ethanol–water yielded *methyl* 4 : 6-O-*benzylidene*-3-*deoxy*-3-*iodo*-α-D-*altroside* (0·257 g., 33·3%), m. p. 163—163·5°, $[\alpha]_D^{23}$ +111° (*c*, 4 in $CHCl_3$) (Found: C, 43·2; H, 4·45. $C_{14}H_{17}O_5I$ requires C, 42·85; H, 4·4%). Some starting material (0·221 g., 42·6%) was also recovered.

When the same experiment was carried out in boiling ether solution for 4 hr., no reaction occurred and 99% of the anhydromannoside was recovered.

(b) *Magnesium bromide.* A solution of the anhydromannoside (1·03 g.) in tetrahydropyran (30 c.c.) was heated under reflux for 2 hr. with anhydrous magnesium bromide (3 g.). An amorphous white precipitate separated. After the mixture had been cooled to room temperature, water (30 c.c.) was added, followed by a slight excess of dilute hydrochloric acid, and the ethereal phase washed and dried in the usual manner before being evaporated to a yellow syrup with a characteristic sweet odour. This was dissolved in a mixture of ether (2 c.c.) and light petroleum (2 c.c.; b. p. 60—80°) and chromatographed on alumina (30 × 1 cm.). Elution with ether–light petroleum (1 : 5) gave as first fractions optically inactive, unidentified mixtures (0·483 g.). Later fractions from the same eluant yielded unchanged starting material (0·184 g.) and chloroform eluted a further 0·106 g. Continuing the chloroform elution gave a colourless syrup (0·491 g.) which crystallised under light petroleum (b. p. 60—80°). This was drained on tile, kept for several days, and recrystallised several times from light petroleum. *Methyl* 4 : 6-O-*benzylidene*-3-*bromo*-3-*deoxy*-α-D-*altroside* (0·21 g., 15·7%) resulting had m. p. 123—124°, $[\alpha]_D^{23}$ +120° (*c*, 0·5 in $CHCl_3$) (Found: C, 48·9; H, 5·0. $C_{14}H_{17}O_5Br$ requires C, 48·7; H, 5·0%).

(c) *Magnesium chloride.* (i) On treatment in ether as described above, but after 8 hours' heating under reflux with an excess of magnesium chloride, 95% of the starting material was recovered. No other product was isolated and no alkalinity was detected on addition of water to the reaction mixture. (ii) A solution of the anhydromannoside (1·04 g.) in tetrahydropyran (25 c.c.) was heated with anhydrous magnesium chloride (2 g.) in a sealed tube at 110° for 8 hr., then at 140° for 4 hr.; it darkened considerably. It was treated as described above, and the dark brown syrup obtained chromatographed on alumina. A fraction containing chlorine was ultimately obtained by elution with chloroform; this was a brown syrup (0·070 g.).

Attempted Methylation of Methyl 4 : 6-O-*Benzylidene*-3-*deoxy*-3-*iodo*-α-D-*altroside.*—The altroside (0·514 g.) was heated under reflux for 18 hr. with silver oxide (1 g.) and methyl iodide (5 c.c.). The product (0·330 g., 95%), isolated in the usual way, was methyl 2 : 3-anhydro-4 : 6-*O*-benzylidene-α-D-mannoside, m. p. and mixed m. p. 146—147°.

When the altroside (87 mg.) in chloroform (1 c.c.) was treated with a solution from sodium (60 mg.) and absolute methanol (3 c.c.) for 20 hr. at room temperature, the same product was isolated (56 mg., 96%).

Reduction of Methyl 4 : 6-O-*Benzylidene*-3-*deoxy*-3-*iodo*-α-D-*altroside*.—The altroside (0·525 g.) in ethanol (20 c.c.) and water (7 c.c.) was boiled with barium carbonate (2 g.) and Raney nickel (*ca.* 15 g.) in ethanol (10 c.c.) with stirring for 2 hr. The mixture was then filtered and evaporated to a colourless syrup which was dissolved in water (10 c.c.) and washed several times with chloroform. Evaporation of the aqueous solution yielded a colourless syrup which was dissolved in ethyl acetate–ethanol, filtered from barium iodide, and concentrated to small volume. Colourless cubic crystals of methyl 3-deoxy-α-D-mannoside separated when the solution was kept at 0° and, recrystallised from acetone, had $[\alpha]_D^{25}$ +134·6° (*c*, 2 in MeOH), m. p. 123·5—124° (Found : C, 47·5; H, 7·92. Calc. for $C_7H_{14}O_5$: C, 47·2; H, 7·92%). Bollinger and Prins (*loc. cit.*) describe this compound as an amorphous solid, showing $[\alpha]_D^{15}$ +108·9° ± 2° (*c*, 2 in MeOH).

The crystalline product was not oxidised by lead tetra-acetate in acetic acid under the conditions described by Hockett and McClenahan (*J. Amer. Chem. Soc.*, 1939, **61**, 1667).

Reduction of Methyl 4 : 6-O-*Benzylidene*-3-*bromo*-3-*deoxy*-α-D-*altroside*.—The altroside (72 mg.) was heated under reflux for 2 hr. with barium carbonate (0·5 g.) and Raney nickel (*ca.* 4 g.) in ethanol (9 c.c.) and water (2 c.c.). Then the cooled solution was filtered and the solids were washed with hot water. The combined filtrates were evaporated to *ca.* 10 c.c., and the aqueous solution was washed several times with chloroform and then evaporated to dryness. The residual colourless viscous syrup was extracted with hot acetone and filtered. When the acetone extract was concentrated and treated with ether, methyl 3-deoxy-α-D-mannoside separated (30 mg., 80%); it had m. p. 123—124° (from acetone–ether) alone or in admixture with the compound described above, and $[\alpha]_D^{22}$ +129·6° (*c*, 1 in MeOH) (Found : C, 47·3; H, 8·2%).

General Procedure for the Reaction of Various Anhydro-sugars and Anhydrohexitols with 0·5N-*Hydrochloric Acid Saturated with Magnesium Chloride*.—The anhydride (0·05 g.) was added to 0·5N-hydrochloric acid saturated with magnesium chloride (3 c.c.), and the mixture kept at room temperature for 15 min. and then titrated with 0·2N-sodium hydroxide. The results obtained are recorded on p. 498.

Methyl 3-*Chloro*-3-*deoxy*-4 : 6-*di*-O-*methyl*-α-D-*glucoside*.—To methyl 2 : 3-anhydro-4 : 6-di-*O*-methyl-α-D-alloside (1 g.) was added 0·5N-hydrochloric acid saturated with potassium chloride (20 c.c.), and the mixture kept overnight at 27°, neutralised with sodium hydroxide, and extracted with ether (5 × 100 c.c.). The extract was dried ($MgSO_4$), filtered and evaporated. The resulting syrup distilled at 130°/0·02 mm. and had n_D^{22} 1·4729 and $[\alpha]_D^{22}$ +147° (*c*, 0·8 in $CHCl_3$), then crystallised. Recrystallised from ether–light petroleum, *methyl* 3-*chloro*-3-*deoxy*-4 : 6-*di*-O-*methyl*-α-D-*glucoside* had m. p. 77—78° $[\alpha]_D^{25}$ +160° (*c*, 1·1 in $CHCl_3$) (Found : C, 45·3; H, 7·2; Cl, 15·1. $C_9H_{17}O_5Cl$ requires C, 44·9; H, 7·1; Cl, 14·8%).

Hydrolysis of Methyl 3-*Chloro*-3-*deoxy*-4 : 6-*di*-O-*methyl*-α-D-*glucoside and Treatment of the Product with Sodium Metaperiodate*.—The chloroglucoside (0·093 g.) was heated with 2N-hydrochloric acid (10 c.c.) at 100° until the rotation was constant {$[\alpha]_D^{25}$ +164° (allowing for hydrolysis of methyl glucoside group), after 20 hr.}, then cooled and made up to 25 c.c. Aliquot parts were added to 5 c.c. of 0·184N-sodium metaperiodate containing a slight excess of sodium hydrogen carbonate. After 1½ hr., 0·92 mol. of periodate was consumed.

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102. *The Mechanism of Hydrolysis of Acid Chlorides. Part VI.* Formolysis of* para-*Substituted Benzoyl Chlorides.*

By E. W. Crunden and R. F. Hudson.

The rates of solvolysis of several *para*-substituted benzoyl chlorides in formic acid–water mixtures have been determined conductimetrically and have been shown to increase regularly with electron release to the carbonyl-carbon atom. The rates of reaction of *p*-toluoyl and benzoyl chloride are almost independent of the water concentration, and addition of formate ions does not increase the rate of reaction of the unsubstituted chloride. On the other hand, the rate of substitution of the *p*-nitro-compound is increased considerably by the addition of formate ions, and is also approximately proportional to the water content.

These results show that the various chlorides react by different mechanisms, *p*-nitro- and 2 : 4 : 6-trinitro-benzoyl chloride participating in an S_N2 type of process whereas compounds containing electron-releasing groups react by an S_N1 type of process. Comparison of the rates of reaction in formic acid and in an aqueous medium of equal solvating power enables the extent of the S_N1 process in 65% aqueous acetone † to be determined approximately to give the following values; *p*-Me, 70%; *p*-H, 40%; *p*-Br, 10%; *p*-NO_2 and 2 : 4 : 6-$(NO_2)_3$, nil. The nature of the S_N1 type of process is briefly discussed.

Considerable evidence has been presented in previous papers of this series * to show that acid chlorides may be hydrolysed by one of two alternative mechanisms depending on the structure of the chloride and the reaction conditions. The mechanistic point has been roughly defined for benzoyl chloride in acetone–water mixtures,[1] and has recently been fixed more accurately.[2] There is no doubt that if we were dealing with a saturated system these two mechanisms could be identified with S_N1 and S_N2 substitutions, but the position is more complex for acyl halides. Thus the influence of a third reactive centre (the carbonyl-oxygen atom) must be taken into account, particularly in view of the observations that electrophilic reagents interact preferentially with this atom.[3]

In addition, the unsaturated nature and the strong polarisability of the carbonyl group raise the possibility that this group may open during the reaction as in the analogous reactions of esters.[4] Recent exchange data [5] show this to be the case, and hence it now appears likely that reaction proceeds through one or more addition intermediates. Owing to the instability of these intermediates the reaction cannot be differentiated kinetically from an S_N2 process at a saturated carbon atom.

The mechanism which resembles an S_N1 process is difficult to follow in aqueous solvents owing to the competing reaction which involves a rate-determining nucleophilic attack. For this reason the present experiments are confined to measurements of solvolysis rates in formic acid and formic acid–water mixtures. Formic acid is a useful solvent for suppressing the bimolecular reaction and promoting a rate-determining ionisation owing to its low nucleophilic power and high solvating power.[6] Thus the reactivity of *p*-nitrobenzoyl chloride, determined mainly by the bond-forming process,[7] is extremely low in formic acid

* Part V, *J.*, 1953, 3352.

† The solvent composition is represented in this way throughout the paper: 65% aqueous acetone refers to a solvent containing 65 ml. of water in a total volume of 100 ml.

[1] Archer and Hudson, *J.*, 1950, 3259.
[2] Gold, Hilton, and Jefferson, *J.*, 1954, 2756.
[3] Dilke, Eley, and Sheppard, *Trans. Faraday Soc.*, 1950, **46**, 261; Surz and Cooke, *Helv. Chim. Acta*, 1954, **37**, 1280.
[4] Bender, *J. Amer. Chem. Soc.*, 1951, **73**, 1626.
[5] Bunton, Lewis, and Llewellyn, *Chem. and Ind.*, 1954, 1154.
[6] Bateman, Hughes, Ingold, and Taher, *J.*, 1940, 979.
[7] Brown and Hudson, *J.*, 1953, 3352.

alone, and increases rapidly with water concentration (Table 4) and on the addition of formate ions (Table 1).

TABLE 1. *The effect of formate ions on the rate of reaction of benzoyl chloride and p-nitrobenzoyl chloride.*

Acid chloride	Concn. (N)	Formate concn. (N)	10^4k_1 (sec.$^{-1}$)	10^2k_2 (l. mole^{-1} sec.$^{-1}$)	$10^{-3}k_2[H_2O]/k_1$
C_6H_5·COCl *	0·0282	0·180	38·6	—	—
		Nil	39·2		
p-NO_2·C_6H_4·COCl †	0·00602	0·0233	—	8·33	3·4
	0·0149	〃	—	8·44	3·44
		Nil	0·185		

* Solvent 4·6% aqueous formic acid at 9°. † Solvent 1·4% aqueous formic acid at 20·1°.

On the other hand, the rates of reaction of benzoyl and *p*-toluoyl chloride are almost independent of the water concentration, and formate ions have no effect. With *p*-bromobenzoyl chloride the rate of the second-order reaction with water becomes appreciable.

These results show therefore that the effect of water on the rate of reaction increases with the tendency for covalent-bond formation at the reactive carbon atom (Table 3).

FIG. 1. *The Hammett relation for* p-*substituted benzoyl chlorides in formic acid.*

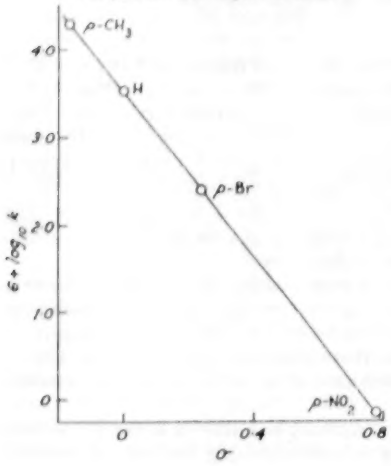


TABLE 2. *Order of reactivities of* p-*substituted benzoyl chlorides. The effect of changing the nucleophilic and solvating conditions of the medium.**

Reactant	NO_2	Br	CH_3	CH_3O
Aniline [a]	8·5	1·5 (Cl)	0·56	—
Ethanol [b]	32	2·5	0·47	0·25
Water [c]	35	3·2	0·55	0·60
			(0·47) [d]	(0·36) [d]
Water [e]	~0	0·086	6·6	V. fast

[a] In benzene. [b] In 40% alcoholic ether.
[c] In 5% aqueous acetone. [d] In 5% aqueous dioxan.
[e] In formic acid.

* The rates are relative to that of the unsubstituted compound.

The rate of reaction in formic acid alone increases with electron release to the carbon atom, and the rate order is the complete reverse of that observed in more nucleophilic media (Table 2).

The results are not sufficiently accurate to afford a value of the rate of reaction of the *p*-nitro-compound in formic acid alone, but extrapolation shows the rate to be very small compared with the values for the other chlorides. The Hammett relation is obeyed for the other three chlorides (Fig. 1), and extrapolation of the log k–σ graph leads to a value of *ca.* 10^{-6} sec.$^{-1}$ at 9° for the nitro-compound. There is some doubt, however, as to whether Hammett's relation holds for S_N1 processes, particularly on substitution of electron-releasing groups.[8] This extrapolated value may therefore be too high.

The very small rate constant for the *p*-nitro-compound in formic acid alone shows that the nucleophilic power of a formic acid molecule is negligible compared with that of a

[8] Kochi and Hammond, *J. Amer. Chem. Soc.*, 1953, **75**, 3442.

water molecule, since bond formation is most important in this reaction. It follows that the considerably greater reactivities of the other chlorides in formic acid refer to processes controlled by solvation forces alone,[9] and hence such rates may be taken to be those of the S_N1 reactions in this medium.

It is of interest to compare these rates with the corresponding rates in a more nucleophilic solvent of equal solvating power. Although solvation in non-aqueous and mixed aqueous systems is too complex to be treated theoretically, empirical values of solvating power may be obtained from the rate constants of a reference reaction known to proceed by the S_N1 mechanism.[10] If change of solvent has no effect on the transition-state structure, it follows that the rates of an ionisation reaction should be equal in solvents of the same solvating power (denoted by Y by Grunwald and Winstein [10]).

With reference to the present results, it is found that formic acid and 65% aqueous acetone have approximately equal Y values. The exact composition of the aqueous solvent giving a medium of solvating power equal to that of formic acid cannot be determined with certainty, since Grunwald and Winstein's law is only approximate and two sets of Y values have been used. These two sets, however, converge rapidly in highly aqueous media and the corresponding values are almost equal in the solvent range considered here. The rate constants change very rapidly with water content, which also adds to the difficulty of estimating the exact Y value.

The appropriate rate constants for the four chlorides in formic acid and 65% aqueous acetone are compared in Table 3.

TABLE 3. *Comparison of the rates of reaction of* p-*substituted benzoyl chlorides in solvents of equal solvating power at* 9°.

Substituent	k_1 (sec.$^{-1}$) in 65% aqueous acetone	k_1 (sec.$^{-1}$) in formic acid	% S_N1 reaction	Effect of water on rate *
CH_3	28×10^{-3}	19×10^{-3}	70	~0
H	$8{\cdot}9 \times 10^{-3}$	$3{\cdot}5 \times 10^{-3}$	40	10%
Br	$2{\cdot}2 \times 10^{-3}$	$2{\cdot}4 \times 10^{-4}$	10	50%
NO_2	$3{\cdot}0 \times 10^{-3}$‡	$1{\cdot}0 \times 10^{-4}$ †	~0	625%

* Increase (%) in rate on changing the water concentration from 0·8 to 5·0 vol. %.
† Obtained from the Hammett relation. ‡ Extrapolated from Brown and Hudson's data.[7]

In all cases the rate is greater in the aqueous acetone solutions, but the greater the case of electron release to the reaction centre the closer are the two corresponding rate constants. Thus the rate of reaction of *p*-toluoyl chloride is almost the same in these two media of considerably different nucleophilic power. This suggests that most of the molecules react by the S_N1 type of mechanism in 65% aqueous acetone. On the other hand, the rate of hydrolysis of *p*-nitrobenzoyl chloride is at least 10^4 times greater in the more nucleophilic solvent, showing that the reaction proceeds entirely by the S_N2 type of process in 65% aqueous acetone, in agreement with previous considerations.

If it is assumed that the rate of the S_N1 type of process is equal in the two solvents, it follows that the excess rate in the aqueous acetone solution is that of the alternative S_N2 process. This comparison thus leads to estimates of the proportion of the reaction proceeding by each mechanism. In this estimation it is assumed that, in each reaction, some molecules are hydrolysed by preliminary ionisation (S_N1), and some by an activated reaction between a nucleophilic water molecule and an acid chloride molecule (S_N2). There is considerable controversy as to whether borderline mechanisms proceed in this way, or whether all the molecules pass through a transition state of intermediate structure.[7, 11]

The available evidence is difficult to explain without assuming that the transition state of an S_N2 process may change as the medium changes to one of greater polarity and solvating

[9] See, however, Strietwieser, *J. Amer. Chem. Soc.*, 1955, **77**, 1117.
[10] Grunwald and Winstein, *ibid.*, 1948, **70**, 846.
[11] Winstein, Grunwald, and Jones, *ibid.*, 1951, **73**, 2700; Swain and Langsdorf, *ibid.*, p. 2813; Bird, Hughes, and Ingold, *J.*, 1954, 634.

power, resulting in increased bond stretching and decreased interaction with the nucleophilic reagent. This leads to an apparent increase in S_N1 character of the reaction, as judged by solvent and substitution effects, although the rate-determining step remains bimolecular. In the present reaction, for example, the rate constant of the *bimolecular* reaction with water and *p*-bromo- is *ca.* 3 times that of *p*-nitro-benzoyl chloride (Table 4), *i.e.*, the reverse of the rate order usually observed for the S_N2 reaction (Table 2).

As the polarity of the medium increases and/or electron-releasing groups accumulate in the alkyl radical, the transition state may change to such an extent that some of the molecules ionise without receiving an energy contribution from the nucleophilic (water) molecule, the remainder of the molecules decomposing by the bimolecular mechanism, with bond-breaking the dominant process. The simultaneous occurrence of both mechanisms in a limited range of reaction conditions follows from the statistical nature of reactions, so that the reacting systems have different energies and configurations, only the mean of which can be determined experimentally.

In the reaction discussed here, independent evidence has been advanced to show that in highly aqueous media, reaction proceeds by both unimolecular and bimolecular processes in a narrow solvent range.[2] The data of Table 3 show the effect of substitution on the extent of participation of the two alternative processes. The reaction of *p*-bromobenzoyl chloride is observed to proceed mainly by the S_N2 process, whereas the unsubstituted chloride reacts to approximately equal extents by both mechanisms, in agreement with previous conclusions.[1]

These results suggest strongly that the rate-determining step of the S_N1 type of mechanism involves electrostatic interaction only between solvent and acid chloride molecule, to give an intermediate with an increased reactivity towards nucleophilic reagents. Analogy with the alkyl halide series suggests that the intermediate is an acyl ion formed in a typical S_N1 process:

$$R{\cdot}COX \overset{\text{Slow}}{\rightleftharpoons} R{\cdot}CO^+ + X^-$$

$$R{\cdot}CO^+ + H_2O \overset{\text{Fast}}{\longrightarrow} R{\cdot}CO_2H + H^+$$

This mechanism is supported by cryoscopic measurements in sulphuric acid indicating the presence of the mesitoyl ion [12] and the formation of acyl derivatives which are reputed to behave as weak electrolytes in sulphur dioxide.[13]

The Reaction of p-*Nitrobenzoyl Chloride.*—As already mentioned, the rate of reaction of this chloride is proportional to the water concentration up to *ca.* 5—10% (v/v) of water. The high reactivity towards formate ions (Table 1) raises the possibility that the reaction proceeds with formate ions due to the ionisation of formic acid promoted by water:

$$H{\cdot}CO_2H \rightleftharpoons H^+ + H{\cdot}CO{\cdot}O^-$$

$$R{\cdot}C(=O){\cdot}X + H{\cdot}CO{\cdot}O^- \longrightarrow R{\cdot}C(=O){\cdot}O{\cdot}CHO + X^-$$

This explanation is in agreement with the direct proportionality between conductivity of the solvent and rate constant (Fig. 2).

This possibility is, however, discounted by the observation that the rate of hydrolysis is strictly of first order over the whole course of the reaction (Fig. 3). If the reaction involved formate ions, the rate constant would decrease continuously owing to the common-ion effect provided that the hydrogen-ion concentration produced in the hydrolysis is greater than that produced by ionisation of the formic acid. The conductivity values show that this requirement is fulfilled; *e.g.*, in 1% aqueous formic acid the conductivity increases from 10^{-5} to $6{\cdot}2 \times 10^{-5}$ mho on hydrolysis of 0·02M-chloride at 9°. Conductivity measurements also show that the mobility of the formate ion is slightly greater than that of the chloride, so the differences in conductivity observed during the reaction may be attributed mainly to changes in hydrogen-ion concentration.

[12] Treffers and Hammett, *J. Amer. Chem. Soc.*, 1937, **59**, 1708.
[13] Seel and Bauer, *Z. Naturforsch.*, 1947, **2b**, 374.

It may therefore be concluded that reaction occurs between water and halide with a rate considerably less than that in acetone or dioxan containing the same concentration of water. Whereas the rate of reaction of the unsubstituted chloride is 220 times greater in 5% aqueous formic acid than in 5% aqueous acetone, the rate of the *p*-nitro-compound is 30 times less and that of the 2 : 4 : 6-trinitro-compound is 150 times less. It is noteworthy that the rate for these last two compounds decreases with increasing dielectric constant and solvating power, although the transition state is more polar than the reactants. It is necessary therefore to resort to a molecular model of the reacting system in order to explain solvent effects in this kind of medium satisfactorily.

Extrapolation of the rate data [7] in acetone–water mixtures leads to a rate constant for the *p*-nitro-compound of *ca.* 10^{-2} sec.$^{-1}$ at 0° in 65% aqueous acetone compared with a value of $1{\cdot}4 \times 10^{-6}$ sec.$^{-1}$ in 1·3% aqueous formic acid. The corresponding activation

FIG. 2. *Relation between the pseudo-unimolecular rate constants for the hydrolysis of* p*-nitrobenzoyl chloride and specific conductivity of formic acid–water mixtures at* 20°.

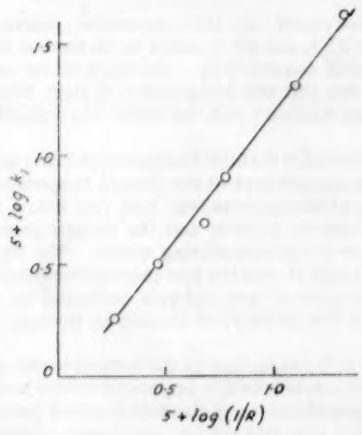
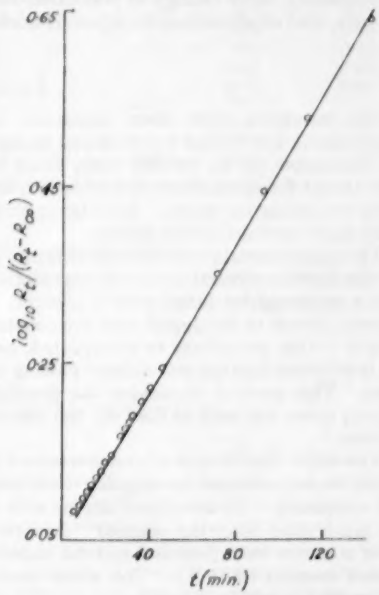


FIG. 3. *First-order plot for the solvolysis of* p*-nitrobenzoyl chloride* (0·0307M) *in* 1·3% *aqueous formic acid at* 40°.



energies are 17·5 and 20 kcal./mole, respectively. Second-order rate constants of 3×10^{-3} and $1{\cdot}9 \times 10^{-5}$ l. mole^{-1} sec.$^{-1}$ are obtained if the rate of the bimolecular reaction is assumed to be proportional to water content. From these values, the entropies of activation in the two media are found to be similar (−6·4 and −5·9 e.u. respectively). The difference in rate of hydrolysis of *p*-nitrobenzoyl chloride in these two solvents is therefore due mainly to the activation energy difference of *ca.* 2·5 kcal. mole^{-1}.

The bimolecular rate constants are compared in media of equal solvating power as it has been suggested that a change in the S_N2 transition state is produced by changing the medium.[7] Thus the reaction of *p*-nitrobenzoyl chloride remains bimolecular in the 5—65% water concentration range, but the contribution of the bond-breaking process increases considerably owing to increased solvation.

The increased energy required for the reaction in formic acid may be attributed to the formation of a stable adduct between formic acid and water molecules, with a bond energy greater than that between individual water molecules :

$$H_2O + H{\cdot}CO_2H \rightleftharpoons H_2O \ldots H{\cdot}CO_2H$$

In 65% aqueous acetone, on the other hand, the reactive water molecule is obtained from a group of water molecules. It is well known that the hydrogen bond in carboxylic acids is appreciably stronger than in alcohols and water. It is difficult to obtain comparable data but the spectroscopic value for the gaseous dimer $(H{\cdot}CO_2H)_2$ of 7·06 kcal./mole may be compared with the value of 5 kcal./mole usually taken for water.[14] The difference of *ca.* 2 kcal. mole^{-1} is of the same order as the difference in activation energy observed. Reduced rates of S_N2 reactions in solvents of high ionising power may therefore be explained semi-quantitatively by the increased bonding energy between solvent molecules and the nucleophilic reagent. When this effect is observed, it may be concluded that covalent-bond formation between the two reacting molecules makes a greater contribution to the activation energy than the bond-breaking process.

The effect is more pronounced in the case of 2 : 4 : 6-trinitrobenzoyl chloride owing to the presence of the three strongly electron-attracting groups. The rate in 15% aqueous formic acid is 150 times less than in 15% aqueous acetone, thus suggesting that the contribution of the bond-breaking process is less than in the case of the *p*-nitro-compound. Consequently, little change in transition-state structure is expected even in highly aqueous solvents, and observations in aqueous acetone appear to support this prediction.[7]

Experimental

The solvolysis rates were measured conductimetrically in the apparatus described previously.[1] The bridge was modified to allow 1 : 10, 1 : 1, and 10 : 1 ratios to be used so that cell resistances up to 100,000 ohms could be measured conveniently. Oil-thermostats were used except for measurements below 10°, for which the cell was immersed in a large Dewar vessel containing ice–water. In order to obtain a sharp balance point, the water was connected to the earth terminal of the bridge.

The experimental procedure was that previously described,[15] the high-resistance cell being used. For the fast reactions the chloride was forced into the solvent kept at the desired temperature, from a micropipette fitted with a plunger. The tip of this pipette was held just below the solvent. Some of the liquid was then sucked back into the pipette, and the plunger pressed sharply. This procedure, twice repeated, caused quite a vigorous stirring action. The liquid was then raised into the cell without passing any air through it, and the first reading immediately taken. This method eliminated the possibility of droplets of acid chloride collecting in and running down the neck of the cell, and also eliminated the necessity of passing air through the solution.

The water–formic acid solutions were not prepared in the same way as the acetone–water and dioxan–water mixtures by weighing water into the pure solvent, as it is impossible to dry formic acid completely. In most cases, drying with phthalic anhydride [16] and distillation gave a product not much drier than the original "AnalaR" sample. For this reason, solutions of suitable water contents were prepared and the water concentrations determined accurately by the Karl Fischer reagent (B.D.H.). The water concentration of solutions up to 5% (v/v) could be determined to within ±0·05%.

In the case of the more concentrated solutions, the samples had to be diluted with methanol before the water estimation, and less consistent results were obtained. The compositions of the more concentrated solutions were determined from a calibration graph of water content, obtained by direct weighing into a sample of formic acid of known (low) water content, against conductivity.

The rate constant was calculated by assuming that the concentration of hydrogen chloride produced is proportional to the conductivity. This was confirmed by making up a solution of *p*-nitrobenzoyl chloride in aqueous formic acid. The chloride was allowed to hydrolyse completely, and then the resistance measured. The solution was successively diluted with formic acid of the same water content, and the resistance measured each time. The reciprocal of the resistance was found to be directly proportional to the concentration of chloride.

If a is the initial concentration of chloride and x the concentration change in time t, it follows that $a = K(1/R_\infty - 1/R_0)$ and $x = K(1/R_t - 1/R_0)$, where R_0, R_t, and R_∞ are the resistances at

[14] Bernal and Fowler, *J. Chem. Phys.*, 1935, **1**, 515; Rowlinson, *Trans. Faraday Soc.*, 1951, **47**, 1200.
[15] Archer, Hudson, and Wardill, *J.*, 1953, 888.
[16] Rodd, "The Chemistry of Carbon Compounds," Elsevier, Amsterdam, 1951, 1, A, p. 542.

zero time, at time t, and at the completion of the reaction respectively, and K is a proportionality constant.

Substitution in the first-order equation shows that

$$k_1 t = 2{\cdot}303 \times \log_{10} R_t(R_0 - R_\infty)/R_0(R_t - R_\infty)$$

so that $\log R_t/(R_t - R_\infty) = k_1 t/2{\cdot}303 + \log R_0/(R_0 - R_\infty)$. The rate constant k_1 is obtained from the graph of $\log R_t/(R_t - R_\infty)$ against t (Fig. 3). R_∞ was measured after a period of 10—20 half-lives. For the slowest reactions, the cell was placed in a thermostat at *ca.* 50° until the reaction was complete, and then returned to the original thermostat for the final reading to be taken. The results of these measurements are given in Tables 4 and 5.

TABLE 4. *The effect of water concentration on the rate of solvolysis of substituted benzoyl chlorides.*

Substituent	Temp.	H_2O (vol. %)	10^4k_1 (sec.$^{-1}$)	Substituent	Temp.	H_2O (vol. %)	10^4k_1 (sec.$^{-1}$)
p-Me	9·0°	1·1	186	*p*-NO_2	10·0°	18·3	3·96
,, ...	,,	5·8	198	,, ...	20·0	1·6	0·18
(H)	9·0	1·0	34·4	,, ...	,,	2·7	0·32
,, ...	,,	1·6	36·8	,, ...	,,	4·6	0·48
,, ...	,,	2·7	38·0	,, ...	,,	5·8	0·78
,, ...	,,	4·6	39·2	,, ...	,,	11·2	2·05
p-Br	9·0	1·1	2·43	,, ...	,,	16·9	9·24
,, ...	20·0	1·1	9·59	,, ...	30·0	16·7	12·4
,, ...	,,	1·9	10·64	,, ...	40·0	1·6	1·63
,, ...	,,	5·8	11·98	,, ...	61·0	1·6	11·6
,, ...	,,	11·2	15·4	2 : 4 : 6-$(NO_2)_3$	61·0	16·9	0·767

(The rates of reaction of *p*-methoxy- and 2 : 4 : 6-trimethyl-benzoyl chlorides are too great to be measured in 1% aqueous formic acid at 9°.)

TABLE 5. *Solvolysis in 65% aqueous acetone.*

Temp.	H_2O (%)	10^4k_1 (sec.$^{-1}$)	Temp.	H_2O (%)	10^4k_1 (sec.$^{-1}$)
	p-Toluoyl chloride			*p*-Bromobenzoyl chloride	
−13·0°	65·0	15·8	9·0°	63·8	20·6
− 4·0	,,	57·9	,,	65·0	22·0
+ 2·0	,,	114	,,	,,	22·0
+ 9·0	,,	278 *	,,	,,	22·5

* Value obtained by extrapolation of the Arrhenius plot.

To determine the effect of added formate ions on the rate, a stock solution of formic acid of known water content containing a known concentration of calcium formate was prepared. The normality of this solution refers to the number of equivalents of formate ion per litre. The resistance of the reaction mixture was found to increase in contrast to the reaction with water alone, showing that chloride ions are less conducting in this medium than formate ions.

In cases where the rate of reaction was found to increase, the rate constant was calculated by assuming that the concentrations of formate and chloride ions are proportional to the corresponding conductivities. If b is the initial concentration of formate ions, it follows that $1/R_0 = Bb$, $1/R_t = Ax + B(b - x)$, and $1/R_\infty = Aa + B(b - a)$, where A and B are proportionality constants connecting concentration and conductivity for chloride and formate ions respectively.

Substitution for $(a - x)$ and $(b - x)$ in $k_2 t = [1/(b - x)] \ln a(b - x)/b(a - x)$, the second-order rate equation, leads to the expression

$$\log_{10} \frac{(1/a - 1/b)/R_0 - (1/aR_\infty - 1/bR_t)}{(1/R_t - 1/R_\infty)} = \frac{k_2(b - a)t}{2{\cdot}303} - \log a$$

The second-order rate constants can then be obtained by plotting the log function against t.

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103. *Trichloromethyl Sulphones and Related Compounds.**

By W. V. Farrar.

Sulphones, $R{\cdot}SO_2{\cdot}CCl_3$, are readily formed by reaction of excess of aqueous sodium hypochlorite with salts of aryl- and arylalkyl-thioacetic acids $R{\cdot}S{\cdot}CH_2{\cdot}CO_2H$. Hypobromite (but not hypoiodite) causes a similar reaction. Smaller amounts of hypochlorite gave dichloromethyl sulphoxides, $R{\cdot}SO{\cdot}CHCl_2$. Some related compounds and reactions are described.

Addition of sodium hypochlorite solution to an alkaline solution of a *S*-substituted mercaptoacetic acid, $R{\cdot}S{\cdot}CH_2{\cdot}CO_2H$, causes precipitation of the corresponding trichloromethyl sulphone, $R{\cdot}SO_2{\cdot}CCl_3$, usually crystalline, according to the reaction: $R{\cdot}S{\cdot}CH_2{\cdot}CO_2Na + 5NaOCl \longrightarrow R{\cdot}SO_2{\cdot}CCl_3 + 2NaCl + 2NaOH + Na_2CO_3$. These sulphones, of which few have hitherto been described, thus become readily accessible. Hypobromites cause a similar reaction, giving tribromomethyl sulphones, but hypoiodites do not.

The products from a number of substituted mercaptoacetic acids are listed in Table 1. The sodium salts of the corresponding sulphonic acid are probably always formed as by-products, by direct oxidation ($R{\cdot}S{\cdot}CH_2{\cdot}CO_2Na + 6NaOCl \longrightarrow R{\cdot}SO_3Na + 2CO_2 + 6NaCl$) rather than by hydrolysis of the trichloromethyl sulphone, since the sulphones are rather stable to alkali. Two such acids were isolated and identified.

To obtain the maximum yield of sulphone, about 7 mols. of hypochlorite instead of the theoretical 5 mols. have to be used. The effect of smaller amounts of hypochlorite was studied systematically with *p*-chlorophenylthioacetic acid (Table 2). The first product isolated (when 2 mols. were used) was the sulphinylacetic acid $p\text{-}C_6H_4Cl{\cdot}SO{\cdot}CH_2{\cdot}CO_2H$; as the amount of hypochlorite was increased, this acid was gradually replaced by the dichloromethyl sulphoxide $p\text{-}C_6H_4Cl{\cdot}SO{\cdot}CHCl_2$ (4—5 mols.), then by the trichloromethyl sulphone (6—7 mols.). Two other dichloromethyl sulphoxides were also prepared by this reaction in moderate yield. A similar reaction with smaller amounts of hypobromite could not be demonstrated in the one case tried; however, Claasz [1] recorded dibromomethyl *o*-nitrophenyl sulphoxide as formed on bromination of *o*-nitrophenylthioacetic acid in acetic acid.

The dichloromethyl sulphoxide is not, however, a genuine intermediate since it is unaffected by hypochlorite, even at 60°, and in solutions buffered with sodium hydrogen carbonate.[2] The course of the reaction is probably:

$$RS{\cdot}CH_2{\cdot}CO_2Na \longrightarrow R{\cdot}SO{\cdot}CH_2{\cdot}CO_2Na \longrightarrow R{\cdot}SO{\cdot}CCl_2{\cdot}CO_2Na \xrightarrow{(A)} R{\cdot}SO_2{\cdot}CCl_2{\cdot}CO_2Na$$

$$\downarrow (B) \qquad\qquad \downarrow$$

$$R{\cdot}SO{\cdot}CHCl_2 \qquad\qquad R{\cdot}SO_2{\cdot}CCl_3$$

Generally, when hypochlorite is present in excess, reaction (*A*) is much faster than (*B*). One case was encountered, however (note 4 to Table 1), where even in presence of excess of hypochlorite the product was a mixture of sulphoxide and sulphone; here reactions (*A*) and (*B*) must have comparable velocities.

Dimorphism seems to be common among these sulphones and sulphoxides; several cases are noted in the Experimental section, in which the first and later preparations gave substances of different m. p.s. In each case a mixture of the two materials had the m. p. of the later ones.

As a special case of the reaction, thiobisacetic acid gives di(trichloromethyl) sulphone; rigorous control of pH is necessary to obtain a good yield (this case was independently discovered elsewhere [3] during the course of the present work). The corresponding reaction with hypobromite gave, under neutral conditions, the expected hexabromo-sulphone, but

* Partly covered by B.P. 728,969.

[1] Claasz, *Ber.*, 1912, **45**, 1023.
[2] Cf. Wood and Travis, *J. Amer. Chem. Soc.*, 1928, **50**, 1226.
[3] James, U.S.P. 2,628,982.

in alkali di(tribromomethyl) sulphoxide was obtained almost quantitatively. When the hypobromite contained free bromine, di(dibromomethyl) sulphone was formed; similarly, the reaction of thiobisacetic acid with chlorine gave di(dichloromethyl) sulphone.

By the action of hypobromite on proteins, Goldschmidt *et al.*[4] isolated an unidentified substance, $C_2O_2Br_6S$, m. p. 134°, which is clearly di(tribromomethyl) sulphone. It may be formed, *via* thiobisacetic acid, by the oxidation of lanthionine $S[CH_2{\cdot}CH(NH_2){\cdot}CO_2H]_2$, itself formed from cystine by the action of alkali.[5] Goldschmidt *et al.* noted that their substance liberated iodine from sodium iodide in acetone, giving a compound, m. p. 164°, for which they gave no analyses; this has now been shown to be di(dibromomethyl) sulphone. It is a general reaction of highly chlorinated and brominated dimethyl sulphones that they are reduced by sodium iodide, one or more of their halogen atoms being replaced by hydrogen. Di(dibromomethyl) sulphone itself is further slowly reduced, giving bromomethyl dibromomethyl sulphone. Di(trichloromethyl) sulphone is reduced only to the pentachloro-compound. Di(tribromomethyl) sulphoxide is also reduced to the pentabromo-sulphoxide. The aryl trichloromethyl sulphones (and dichloromethyl sulphoxides) give only a slight colour of iodine after 1 hour's refluxing with sodium iodide in acetone.

p-Chlorophenyl trichloromethyl sulphone is slowly hydrolysed by boiling dilute aqueous sodium hydroxide, giving sodium *p*-chlorobenzenesulphonate and chloride ions. Chloroform was not detected.

Aryl dichloromethyl sulphoxides react unexpectedly with cold concentrated sulphuric acid, after a short induction period, yielding hydrogen chloride and the diaryl disulphide in moderate yield.

Related Reactions.—The reaction of hypochlorite with sodium *p*-chlorophenylthiomethanesulphonate [6] gave the salt (I). Evidently desulphonation, unlike decarboxylation, does not occur under these conditions.

(I) $p\text{-}C_6H_4Cl{\cdot}SO_2{\cdot}CCl_2{\cdot}SO_2Na$ $\qquad$ $CCl_3{\cdot}SR{:}N{\cdot}SO_2{\cdot}C_6H_4Me\text{-}p$ (II)

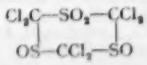
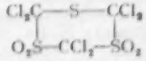
An attempt was made to modify the synthesis of trichloromethyl sulphones so as to give a trichloromethyl sulphoximide, by the reaction, first of chloramine-T, then of hypochlorite, on an arylthioacetic acid :

$$RS{\cdot}CH_2{\cdot}CO_2Na \longrightarrow C_7H_7{\cdot}SO_2{\cdot}N{:}SR{\cdot}CH_2{\cdot}CO_2Na \longrightarrow C_7H_7{\cdot}SO_2{\cdot}N{:}SRO{\cdot}CCl_3$$

When R was 2 : 4-dichlorophenyl, the only nitrogenous product isolated was the sulphimide (II), the final oxidation to sulphoximide not having occurred.

A compound of type (II) has probably been encountered previously, but not recognised. Clarke, Kenyon, and Phillips,[7] by reaction between ethylthioacetic acid and chloramine-T, obtained a small yield of a substance whose formula appeared to be $C_{10}H_{12}O_4NCl_2S_2$, but did not propose a structure to fit this. If their chlorine analysis is wrong, however, the remaining figures agree well with those for the sulphimide (II; R = Et) (Found : C, 34·4; H, 3·7; N, 4·1; S, 18·2; Cl, 20·9. $C_{10}H_{12}O_2NCl_3S_2$ requires C, 34·45; H, 3·45; N, 3·95; S, 18·35; Cl, 30·6%).

Hypochlorite did not react with 1 : 3 : 5-trithian in alkali, but buffering with sodium hydrogen carbonate initiated an exothermic reaction, giving a substance $C_3O_4Cl_6S_3$, whose

(III)  $\qquad$  (IV)

infrared spectrum shows the presence of sulphone and the absence of sulphoxide groups, indicating that the formula is (IV) and not (III). Similar treatment of trithian trisdioxide gave the known hexachloro-trisulphone.[8]

Related Compounds.—For comparison with trichloromethyl sulphones, two aryl

[4] Goldschmidt, Wiberg, Nagel, and Martin, *Annalen*, 1927, **456**, 33.
[5] Horn, Jones, Breese, and Ringel, *J. Biol. Chem.*, 1941, **138**, 141.
[6] Barber, Cottrell, Fuller, and Green, *J. Appl. Chem.*, 1953, **3**, 253.
[7] Clarke, Kenyon, and Phillips, *J.*, 1930, 1225.
[8] Camps, *Ber.*, 1892, **25**, 247.

dichloromethyl sulphones were prepared by reaction of the corresponding sodium arenesulphinates with chloroform. This reaction presented no difficulty, in spite of Otto and Otto's statement [9] that sodium benzenesulphinate did not react with chloroform even at 160°. No trichloromethyl sulphone could be obtained, however, in the corresponding reaction with carbon tetrachloride.

Some attempts were also made to make α-disulphones $R{\cdot}SO_2{\cdot}SO_2{\cdot}CCl_3$. Di(trichloromethyl) disulphone was not produced by the permanganate oxidation of sodium trichloromethanesulphinate; instead, the product was hexachloroethane. Battegay and Kern [10] who studied the action of metals on trichloromethanesulphonyl chloride (a reaction which would also be expected to give the above disulphone) obtained a volatile substance of m. p. *ca.* 180°; repetition of their work has shown this also to be impure hexachloroethane. A new carbon–carbon bond must therefore be formed, with loss of sulphur dioxide. The compound p-$C_6H_4Cl{\cdot}SO_2{\cdot}S{\cdot}CCl_3$ (described [11] since the completion of this work) was recovered unchanged in attempts at its oxidation to the disulphone.

Experimental

Preparation of Trichloromethyl Sulphones.—General method. A solution (neutral or alkaline) of the substituted sodium mercaptoacetate was added rapidly to a stirred solution (8 equivs.)

Table 1. *Sulphones*, $R{\cdot}SO_2{\cdot}CX_3$.

R	Yield (%)	M. p.	Description	Formula	Found (%) C	H	Cl	Calculated (%) C	H	Cl	Note
Chlorides (X = Cl).											
Ph	87	88°	Needles	$C_7H_5O_2Cl_3S$	32·7	2·1	—	32·4	1·95	—	1
p-C_6H_4Cl	82	146	Prisms	$C_7H_4O_2Cl_4S$	28·65	1·4	48·3	29·1	1·7	47·9	
2 : 4-$C_6H_3Cl_2$	68	98	,,	$C_7H_3O_2Cl_5S$	25·8	1·0	—	25·6	0·95	—	2
2 : 5-$C_6H_3Cl_2$	65	111	,,	,,	—	—	54·7	—	—	54·05	3
2 : 4-$NO_2{\cdot}C_6H_3Cl$	5	163	,,	$C_7H_3O_4NCl_4S$	24·8	1·1	—	24·7	0·9	—	
o-C_6H_4Me	50	50	,,	$C_8H_7O_2Cl_3S$	35·4	2·8	—	35·1	2·55	—	—
2 : 4-C_6H_3MeCl	55	100	,,	$C_8H_6O_2Cl_4S$	31·5	1·9	—	31·2	2·0	—	
2 : 5 : 4-$C_{10}H_2Me_2Cl$	*ca.* 20	150—151	Hexagonal tablets	$C_9H_8O_2Cl_4S$	33·7	2·5	—	33·55	2·5	—	4
o-$NO_2{\cdot}C_6H_4$	83	112—113	Pale yellow needles	$C_7H_4O_4NCl_3S$	28·0	1·1	34·7	27·6	1·3	34·95	5
p-$NO_2{\cdot}C_6H_4$	75	174—175	Pale yellow small needles	,,	—	—	34·9	—	—	34·95	
2-$C_{10}H_7$	90	158—159	Needles	$C_{11}H_7O_2Cl_3S$	—	—	34·1	—	—	34·4	
Ph·$[CH_2]_2$	50	65	,,	$C_9H_9O_2Cl_3S$	37·8	3·6	—	37·6	3·2	—	6
2-Benzothiazolyl	24	142—143	Platelets	$C_9H_4O_2NCl_3S_2$	31·0	1·3	33·2	30·35	1·2	33·6	7
Bromides (X = Br).											
Ph	81	147	Needles	$C_7H_5O_2Br_3S$	21·6	1·5	—	21·4	1·3	—	8
2 : 4-$C_6H_3Cl_2$	90	132—133	Heavy prisms	$C_7H_3O_2Cl_2Br_3S$	18·6	0·8	—	18·2	0·65	—	

Notes to Table 1. (1) Troeger and Muller [12] report m. p. 121·5° for an unidentified compound $C_7H_5O_2Cl_3S$, which from its method of preparation is certainly this sulphone. Sanna [13] gives m. p. 121°; Böhme and Gran [14] give m. p. 87°. (2) First obtained as needles, m. p. 88·5°. (3) Addition of sodium chloride to the filtrate from the sulphone gave sodium 2 : 5-dichlorobenzenesulphonate, platelets from ethanol (Found : Na, 9·1. Calc. for $C_6H_3O_3Cl_2SNa$: Na, 9·2%). (4) Accompanied by an approximately equal amount of the corresponding *dichloromethyl sulphoxide*, needles, m. p. 103—104° (Found : C, 39·5; H, 3·2. $C_9H_9OCl_3S$ requires C, 39·8; H, 3·3%), separated by fractional crystallisation from light petroleum, in which the sulphoxide is more soluble. (5) Indications of an unstable form, m. p. *ca.* 96°. The stable form (Found : N, 4·4; S, 10·8. $C_7H_4O_4NCl_3S$ requires N, 4·6; S, 10·5%) crystallised from benzene–light petroleum. (6) The starting material, phenethylthioacetic acid, was made according to Holmberg.[15] The sulphone crystallised only on storage for about a week; recrystallisation was from light petroleum (b. p. 60—80°). (7) Addition of sodium chloride to the filtrate from sulphone gave sodium benzothiazole-2-sulphonate, platelets from ethanol. (8) Lit.,[16] m. p 145°.

[9] Otto and Otto, *Ber.*, 1888, **21**, 1691.
[10] Battegay and Kern, *Bull. Soc. chim. France*, 1927, **41**, 46.
[11] Lo, Wilson, and Croxall, *J. Amer. Chem. Soc.*, 1954, **76**, 1704.
[12] Troeger and Müller, *Arch. Pharm.*, 1914, **252**, 51.
[13] Sanna, *Gazzetta*, 1942, **72**, 305.
[14] Böhme and Gran, *Annalen*, 1953, **381**, 133.
[15] Holmberg, *J. pract. Chem.*, 1934, **141**, 93.
[16] Troeger and Hille, *ibid.*, 1905, **71**, 128.

of sodium hypochlorite ("bleach liquor"; approx. 30% w/v of NaOCl, 12—13% "active chlorine"). External cooling was used if necessary to keep the temperature below about 45°. Precipitation of the sulphone usually began within a few minutes and was complete in 2—5 hr. *Compounds* made by this method are listed in Table 1; only one sulphone was grossly impure when precipitated (see note 4). Crystallisations, unless otherwise stated, were from ethanol or aqueous ethanol.

The bromine compounds were made by a similar method, by using an approx. 10% sodium hypobromite solution.

The following acids were vigorously oxidised by hypochlorite, but no neutral products could be isolated: mercaptoacetic acid, dithiobisacetic acid, phenylmethanebis(mercaptoacetic acid) (benzoic acid formed), methanetris(mercaptoacetic acid), tri(carboxymethyl)amine, and di(carboxymethyl)thetin. *p*-Chlorophenylselenoacetic acid [17] was oxidised by excess of hypochlorite to water-soluble substances; smaller amounts of hypochlorite gave di-*p*-chlorophenyl diselenide as the only neutral product. 2 : 4-Dichlorophenoxyacetic acid did not react with hypochlorite.

Reaction of p-*Chlorophenylthioacetic Acid with Various Amounts of Hypochlorite.*—To six solutions of *p*-chlorophenylthioacetic acid (10 g.) in 0·4N-sodium hydroxide (200 c.c.) were added, severally, 2, 3, 4, 5, 6, and 7 equivs. of sodium hypochlorite; the mixtures were then kept for 3 days at 20—25°. The solids which separated were filtered off; the filtrates were acidified, and the precipitated acid (if any) also examined. Results are summarised in Table 2. Of the

TABLE 2.

NaOCl (equivs.)	Neutral product	Acid product
2	0·5 g.; m. p. 65° (*A*)	7·0 g.; m. p. 125° (*B*)
3	3·4 g.; m. p. 65° (*A*)	3·0 g.; m. p. 125° (*B*)
4	3·9 g.; m. p. 65° (*A*)	2·0 g.; m. p. 120° * (*C*)
5	10·0 g.; m. p. 65° (*A*)	1·0 g.; m. p. 110—120° * (*C*)
6	7·0 g.; m. p. 130—140° (*D*)	2·0 g.; m. p. 60—110° * (*C*)
7	12·5 g.; m. p. 140° (*D*)	Nil

* With effervescence.

products, *A* is *p*-chlorophenyl dichloromethyl sulphoxide; *D* is the trichloromethyl sulphone (m. p. 146°); *B*, needles (from aqueous ethanol), m. p. 126—127°, is *p-chlorophenylsulphinylacetic acid* (Found: C, 43·5; H, 3·7. $C_8H_7O_3ClS$ requires C, 43·9; H, 3·25). The acid (or mixture of acids) *C* was not identified; it decomposed on attempted recrystallisation.

Preparation of Dichloromethyl Sulphoxides.—A solution (neutral or alkaline) of the sodium salt of the substituted mercaptoacetic acid was mixed with sodium hypochlorite solution (approximately 5 equivs.) and set aside for 24 hr. The *dichloromethyl sulphoxide* was precipitated as an oil which crystallised on seeding or scratching. The products were the *phenyl*, hexagonal tablets (from benzene–light petroleum), m. p. 32—34° (30% yield) (Found: Cl, 34·5. $C_7H_6OCl_2S$ requires Cl, 34·0%), *p-chlorophenyl*, m. p. 66° (from light petroleum) (80% yield) (Found: C, 34·6; H, 2·1; Cl, 43·2. $C_7H_5OCl_3S$ requires C, 34·5; H, 2·1; Cl, 43·7%), and *2-naphthyl derivatives*, needles (from aqueous ethanol), m. p. 89° (54% yield) (Found: Cl, 27·4. $C_{11}H_8OCl_2S$ requires Cl, 27·4%). The second product was first obtained as needles, m. p. 59—60°, from aqueous ethanol.

Di(trichloromethyl) Sulphone.—A mixture of sodium sulphide nonahydrate (96 g.) and sodium chloroacetate (from 76 g. of chloroacetic acid) in water (500 c.c.) was refluxed for 1 hr., then made acid with hydrochloric acid to Congo-red and added dropwise to "bleach liquor" (1500 c.c.) with stirring. The temperature was not allowed to exceed 45°. The sulphone was precipitated as a lachrymatory oil, which crystallised (68·5 g.); it recrystallised from a small amount of light petroleum as prisms m. p. 37—38° (lit.,[18] m. p. 35·7—36·0°), but is otherwise very soluble in organic solvents. It is volatile in steam without much decomposition, but is rapidly hydrolysed by refluxing 2N-sodium hydroxide (Found: Cl, 70·8; S, 10·6. Calc. for $C_2O_2Cl_6S$: Cl, 70·75; S, 10·6%).

Di(dichloromethyl) Sulphone.—A solution of thiobisacetic acid, made as above, was stirred at 80° and treated with chlorine for 6 hr. The almost pure sulphone crystallised as needles, m. p. 104° (40 g.) (Found: C, 10·4; H, 0·9. Calc. for $C_2H_2O_2Cl_4S$: C, 10·35; H, 0·9%). Truce *et al.*[18] report m. p. 103·8—104·5°.

[17] Béhagel and Rollmann, *J. prakt. Chem.*, 1929, **123**, 329.
[18] Truce, Birum, and McBee, *J. Amer. Chem. Soc.*, 1952, **74**, 3594.

Di(tribromomethyl) Sulphoxide and Sulphone.—(i) To a stirred solution of sodium hydroxide (64 g.) in water (1 l.), bromine (128 g.) was added dropwise at 10—25°. When reaction was complete, sodium hydrogen carbonate (20 g.) was added, followed gradually by thiobisacetic acid (15 g.) in water (150 c.c.). After 1 hr., the solid was collected, dried, and recrystallised from light petroleum, forming prisms, m. p. 134° (11 g.) (Found : Br, 84·1. Calc. for $C_2O_2Br_6S$: Br, 84·5%). Reported [19] m. p.s are 132·5° and 134°. This substance has a characteristic " hypobromite " smell.

Addition of dilute sulphuric acid to the filtrate from the above sulphone gradually precipitated di(dibromomethyl) sulphone (20 g.), m. p. 160—162° (lit.,[20] m. p. 161°) forming prisms from chloroform (Found : Br, 77·4. Calc. for $C_2H_2O_2Br_4S$: Br, 78·0%). This sulphone is also formed when thiobisacetic acid reacts with hypobromite which contains excess of bromine.

(ii) When the reaction as described under (i) is carried out without addition of sodium hydrogen carbonate, the product (31 g.) is *di(tribromomethyl) sulphoxide*, plates (from ethanol), having a very characteristic smell, m. p. *ca.* 95—98° (decomp.) (Found : C, 4·1; H, 0·0; Br, 87·0, 86·7. C_2OBr_6S requires C, 4·35; H, 0·0; Br, 86·95%). When quantities of *ca.* 1 g. are heated alone above the m. p. they decompose with some violence, evolving vapours smelling of carbonyl chloride and leaving a residue of the sulphone.

Sodium Iodide Reactions.—General method. The substance, dissolved in acetone, was mixed with acetone containing an excess of sodium iodide. Iodine was liberated immediately, and the mixture was kept at room temperature until reaction appeared to be complete (2—24 hr.). Excess of aqueous sodium hydrogen sulphite was then added, and the resulting precipitate recrystallised. In this way, di(trichloromethyl) sulphone gave dichloromethyl trichloromethyl sulphone, m. p. 35° (lachrymatory) (Found : C, 9·2; H, 0·5; S, 12·3. Calc. for $C_2HO_2Cl_5S$: C, 9·05; H, 0·4; S, 12·0%). Truce *et al.*[18] record m. p. 36·2—36·4°. Further reaction was very slow.

Di(tribromomethyl) sulphone gave di(dibromomethyl) sulphone, m. p. 160—162°. A further slow reaction occurred, giving *bromomethyl dibromomethyl sulphone*, m. p. 67° (needles from light petroleum) (Found : C, 7·6; H, 1·0; S, 9·7. $C_2H_2O_2Br_3S$ requires C, 7·25; H, 0·9; S, 9·65%). The hexabromo-sulphoxide gave *dibromomethyl tribromomethyl sulphoxide*, odourless prisms (from ethanol), m. p. 117° (Found : S, 7·0; Br, 83·9, 84·7. C_2HOBr_5S requires S, 6·8; Br, 84·55%).

Sodium Dichloro-p-chlorobenzenesulphonylmethanesulphonate (I).—Sodium *p*-chlorophenylthiomethanesulphonate [6] (7 g.), in warm water (50 c.c.), was treated with " bleach liquor " (50 c.c.). The starting material was immediately salted out, then the temperature rose, with replacement of the original leaflets by needles (5·25 g.). The product recrystallised from a little hot water as prisms of *dihydrate* (Found : C, 21·6; H, 2·2; Cl, 26·6. $C_7H_4O_5Cl_3S_2Na,2H_2O$ requires C, 21·15; H, 2·05; Cl, 26·8%).

S-2 : 4-*Dichlorophenyl*-S-*trichloromethyl*-N-*toluene*-p-*sulphonylsulphimide* (II; R = 2 : 4-$Cl_2C_6H_3$).—2 : 4-Dichlorophenylthioacetic acid (5 g.), in 2N-sodium hydroxide (100 c.c.), was treated with chloramine-T (trihydrate; 12 g.) in water (100 c.c.) and kept for 3 days : there was no visible change. Excess of " bleach liquor " (50 c.c.) was then added, and the resultant solid (8 g.) collected after 2 hr. This material seemed to consist of about equal amounts of the sulphimide and 2 : 4-dichlorophenyl trichloromethyl sulphone. Repeated crystallisation from benzene, in which the former compound is less soluble, gave the *sulphimide* (1·8 g.) as needles, m. p. 124° (decomp., after darkening above 120°) (Found : C, 36·0; H, 1·9; N, 3·1; Cl, 38·4. $C_{14}H_{10}O_2NCl_5S_2$ requires C, 36·05; H, 2·15; N, 3·0; Cl, 38·1%).

Hexachloro-1 : 3 : 5-*trithian* 1 : 1 : 3 : 3-*Tetraoxide* (IV).—Powdered trithian (20 g.) was added during 30 min. to a cooled, stirred mixture of " bleach liquor " (400 c.c.), water (400 c.c.), and sodium hydrogen carbonate (20 g.). After overnight stirring, the solid (38 g.) was collected, dried, and recrystallised twice from acetone, giving prisms (22 g.), m. p. 203—204° (decomp.) (Found : C, 8·7, 9·1; H, 0·2, 0·0; Cl, 52·4. $C_3O_4Cl_6S_3$ requires C, 8·8; H, 0·0; Cl, 52·1%). The mother-liquors probably contained di(trichloromethyl) sulphone. Decomposition of the tetraoxide at its m. p. caused the evolution of thiocarbonyl chloride (identified by its reaction with aniline to give diphenylthiourea). The tetraoxide liberates iodine from sodium iodide in acetone, but the product was not investigated.

Mr. M. St. C. Flett, who measured the infrared spectrum, reported : " A 5% solution in carbon tetrachloride showed bands at 1370—1410 and 1170—1190 cm.$^{-1}$, fairly close to the

[19] Reuterskiöld, *J. prakt. Chem.*, 1931, **129**, 121 ; ref. 4.
[20] Jönsson, *Svensk kem. Tidskr.*, 1922, **34**, 194.

positions characteristic of a sulphone group. There was no band near 1050 cm.$^{-1}$ in the position characteristic of a sulphoxide group."

p-*Chlorophenyl Dichloromethyl Sulphone.*—A mixture of chlorobenzene-*p*-sulphinic acid (50 g.), chloroform (60 c.c.), and sodium hydroxide (30 g.) in water (450 c.c.) was refluxed for 10 hr. The product was extracted with chloroform : evaporation of the extracts gave 42 g. (57%) of crude sulphone. Acidification of the aqueous layer gave a 20% recovery of sulphinic acid. The *sulphone* formed prisms (from ethanol), m. p. 122° (Found : Cl, 40·7. $C_7H_5O_2Cl_3S$ requires Cl, 41·0%). Dichloromethyl *p*-tolyl sulphone, made in the same way, had m. p. 118° (lit., m. p. 114°).

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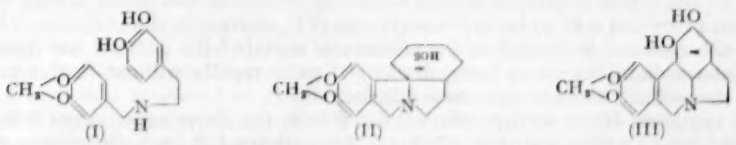
104. *The Oxidation of Some 3 : 4-Dihydroxyphenethylamines.*

By E. J. FORBES.

3 : 4-Dihydroxy-*N*-(3 : 4-methylenedioxybenzyl)phenethylamine (I) and its *N*-3 : 4-dihydroxybenzyl analogue (IV) have been oxidised to indoles by gaseous oxygen in the presence of the enzyme polyphenol oxidase and by other agents. The structures of the products, isolated as their methyl ethers, have been proved by independent syntheses.

ALTHOUGH the oxidative coupling of aromatic nuclei has been achieved in other fields, it has not as yet been accomplished in the alkaloid series. Such a reaction has been postulated by Robinson [1] as a step in the biogenesis of the alkaloids of the morphine and aporphine groups. In an attempt to realise this process in the laboratory, Robinson and Sugasawa [2] and Schöpf and Thierfeld [3] oxidised laudanosoline under a variety of conditions. The product, however, was a tetrahydrodibenzopyrrocoline and not norglaucine.

In a biogenetic scheme for lycorine, the oxidation of the amine (I) [4] or its biogenetic equivalent [5] was envisaged as an intermediate step. This could lead either to a blocked hydroaromatic structure (II) [5] or to a reduced phenanthridine (III).[6] Either course involves the formation of an indole ring and the oxidative coupling of two aromatic nuclei. In the oxidation of laudanosoline the prior formation of the indole ring in laboratory experiments stereochemically precluded coupling of the aromatic nuclei, but with amine (I) this would not be so.

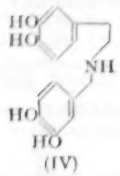


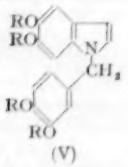
Harley-Mason [4] oxidised the closely related amine (IV) with potassium ferricyanide in the presence of sodium hydrogen carbonate. The product was undoubtedly the indole (V; R = H), though this was not in fact proved. In the present work this point has been settled, and further efforts have been made to oxidise the amine (IV) beyond the indole stage. The analogous amine (I) has also been submitted to oxidative procedures, but as with the amine (IV) aromatic coupling was not achieved.

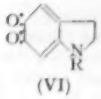
Raper [7] oxidised a series of 3 : 4-dihydroxyphenethylamines to 5 : 6-dihydroxyindoles with gaseous oxygen in the presence of the enzyme tyrosinase, obtained from meal worms.

[1] Robinson, *J.*, 1931, **3163**; *J. Roy. Soc. Arts*, 1948, **96**, 807.
[2] Robinson and Sugasawa, *J.*, 1932, 789.
[3] Schöpf and Thierfeld, *Annalen*, 1932, **497**, 22.
[4] Harley-Mason, *J.*, 1953, 200.
[5] Forbes, Harley-Mason, and Robinson, *Chem. and Ind.*, 1953, 946.
[6] Kondo and Uyeo, *Ber.*, 1937, **70**, 1087; Kelly, Taylor, and Wiesner, *J.*, 1953, 2094.
[7] Raper, *Biochem. J.*, 1927, **21**, 89.

This reaction involves the formation of an intermediate *o*-quinone (VI), which then undergoes autoreduction to the dihydroxyindole in the presence of aqueous sulphur dioxide. It has now been found that a preparation of polyphenol oxidase, readily obtained from mushrooms, gives excellent results. Preliminary experiments, designed to test the effectiveness and specificity of the enzyme, were made on 3 : 4-dihydroxyphenethylamine according to Blaschko and Schlossmann's method.[8] Solutions of the amine hydrochloride


(IV)


(V)


(VI)

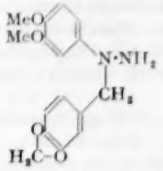
in a phosphate buffer were incubated in oxygen with the enzyme preparation, and the uptake of oxygen was measured manometrically. After a rapid uptake of two atoms of oxygen, as required for the formation of the *o*-quinone (VI; R = H), there was practically no further absorption. With the amine (I) there was again a rapid initial uptake of two atoms of oxygen, as expected, but with the amine (IV) a rapid uptake of four atoms was recorded. This latter figure must include two atoms for the formation of the *o*-quinone (VI), one atom for the catechol group which does not participate in ring-closure, and, most disappointingly as the sequel shows, the fourth atom must have been used in dehydrogenating the *o*-quinone nucleus (VI). From these experiments the time required for complete oxidation and also the concentrations of solutions which could be employed without the *o*-quinone's being precipitated were determined. For preparative purposes, a suspension of the enzyme preparation in a dilute solution of the amine hydrochloride in a phosphate buffer of pH 7 was treated with a rapid stream of oxygen. A deep-red colour, due to *o*-quinone formation, rapidly developed. After an appropriate period, as determined by the manometric experiments, the oxygen stream was interrupted. Acetic acid was added to inactivate the enzyme which was then removed. Following the addition of aqueous sulphur dioxide, the solution was put aside. Overnight the *o*-quinone (VI) underwent autoreduction to the 5 : 6-dihydroxyindole, which was methylated before isolation. The products from the amines (I) and (IV) were the indoles (VIII; R = H) and (V; R = Me), no aromatic coupling having taken place. Potassium iodate gave similar results. It is of interest that in Raper's experiments and in the present series the oxidation proceeded only so far as the *o*-quinone (VI), whereas in the oxidation of laudanosoline with chloranil in alcohol in the presence of acetate [2] the quinone was formed only as an intermediate, its colour being discharged quite rapidly without further treatment to give the product, albeit in this case a dihydroindole.

The syntheses of the methyl ethers isolated from the above experiments followed the same path, which will be described only for 5 : 6-dimethoxy-1-(3 : 4-methylenedioxybenzyl)-indole (VIII; R = H). 3 : 4-Dimethoxyaniline condensed readily with piperonaldehyde in refluxing alcohol to give the Schiff's base, 3 : 4-dimethoxy-*N*-(3 : 4-methylenedioxybenzylidene)aniline. This compound was so readily hydrogenated that considerably more than the mol. of hydrogen required for the azomethine linkage was absorbed when either Adams catalyst or palladium on strontium carbonate was used. With Raney nickel, the reduction stopped abruptly after one mol. of hydrogen had been absorbed. The resulting 3 : 4-dimethoxy-*N*-(3 : 4-methylenedioxybenzyl)aniline showed little tendency to darken in the air. It gave a transient red colour, changing to bluish-green, with ferric chloride, probably as the result of demethylation of the group *para* to the nitrogen atom followed by quinone formation (cf. the synthesis of asaronic acid [9]).

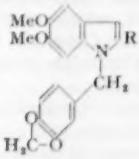
3 : 4-Dimethoxy-(*N*-3 : 4-methylenedioxybenzyl)aniline was converted into the nitrosamine, which was reduced by zinc dust and acetic acid to the hydrazine (VII). This

[8] Blaschko and Schlossmann, *J. Physiol.*, 1940, **98**, 1, 130.
[9] Luff, Perkin, and Robinson, *J.*, 1910, 1131.

reduction caused much difficulty, and the yields (based on subsequent products) were low. Catalytic reduction yielded only by-products (cf. Paal and Yao [10]). In practice the hydrazine was not isolated, but was straightway condensed with pyruvic acid and the resultant hydrazone was cyclised with sulphuric acid to 5 : 6-dimethoxy-1-(3 : 4-methylenedioxybenzyl)indole-2-carboxylic acid (VIII; R = CO_2H). Overall, the yield of indolecarboxylic acid from the nitrosamine varied from 18 to 27%. When *cyclo*hexanone was used instead of pyruvic acid, the yield of the carbazole was rather better (40%), owing to the greater facility with which the hydrazone underwent cyclisation.



(VII)



(VIII)

The indolecarboxylic acid (VIII; R = CO_2H) when warmed with Ehrlich's reagent gave a magenta colour, which disappeared on cooling. When heated to 2—3° above its melting point for a few minutes, the acid was decarboxylated smoothly to give a high yield of 5 : 6-dimethoxy-1-(3 : 4-methylenedioxybenzyl)indole (VIII; R = H), identical with the product of oxidation of the secondary amine (I).

With veratraldehyde in place of piperonaldehyde the above series of reactions gave 5 : 6-dimethoxy-1-(3 : 4-dimethoxybenzyl)indole (V; R = Me), identical with the product of the oxidation of the secondary amine (IV) with oxygen, potassium iodate, or potassium ferricyanide (cf. Harley-Mason [4]).

Experimental

Oxidation of 3 : 4-*Dihydroxy*-N-(3 : 4-*methylenedioxybenzyl)phenethylamine with Gaseous Oxygen.*—A preparation of the enzyme, polyphenol oxidase, was made as follows. Fresh mushrooms (195 g.) were passed through a meat-mincer into ice-cold acetone (1·5 l.). The solid was collected, washed twice with ice-cold acetone, and pressed between filter papers. After drying overnight in the air, the solid (7·5 g.) was ground to a fine powder and used without further treatment. (*a*) Preliminary experiments were carried out with 3 : 4-dihydroxyphenethylamine hydrochloride according to Blaschko and Schlossmann's method.[8] Solutions of the hydrochloride were incubated with the enzyme preparation and the uptake of oxygen was measured manometrically. The main bulbs of the manometric flasks contained suspensions of the enzyme powder (the strongest being 100 mg. of powder in 100 c.c. of solution) in a phosphate buffer of pH 7·4 (2·7 c.c.), whilst in the side bulb was placed a solution (0·02M; 0·3 c.c.) of 3 : 4-dihydroxyphenethylamine hydrochloride. The manometers were filled with oxygen, and the flasks were then incubated at 17°. When the contents of the two bulbs were mixed, absorption of oxygen commenced immediately and the solutions became red, owing to *o*-quinone formation. With the most concentrated enzyme suspension, gas absorption was complete (2 atoms) within 6 min.; the more dilute preparations required longer. A similar series of experiments was then carried out with 3 : 4-dihydroxy-*N*-(3 : 4-methylenedioxybenzyl)phenethylamine hydrochloride, in which the concentration of the enzyme suspension remained constant whilst the strength of the hydrochloride was varied from 0·02M to 0·004M. The *o*-quinone was not precipitated at a concentration of 0·004M, and oxygen uptake was complete (2 atoms) within 10 min.

(*b*) A rapid stream of oxygen was bubbled through a suspension of the enzyme preparation (3·5 g.) in a solution of the hydrochloride (0·5 g.) in water (500 c.c.) and a 0·03M-phosphate buffer (50 c.c.; pH 7·4); the flask was shaken meanwhile. The liquid immediately became red, the colour gradually deepening. After 10 min., the oxygen stream was stopped, 1% acetic acid (10 c.c.) was added to the mixture, and the liquid was filtered. Saturated aqueous sulphur dioxide (10 c.c.) was added to the deep-red filtrate, which was then left overnight. After filtration, the straw-coloured liquid was evaporated under reduced pressure to about 20 c.c. The product was then methylated under hydrogen with 20% sodium hydroxide (6·5 c.c.) and

[10] Paal and Yao, *Ber.*, 1930, **63**, 57.

dimethyl sulphate (3 c.c.). When the initial reaction was over, the mixture was heated (steam-bath) for 1 hr. After cooling, the mixture was extracted with a large volume of ether, and the ethereal extract was washed quickly with 2% sulphuric acid. The solution was dried (K_2CO_3) and evaporated to dryness, leaving buff crystals (0·2 g.). Recrystallisation from methanol afforded 5 : 6-dimethoxy-1-(3 : 4-methylenedioxybenzyl)indole in needles, m. p. 93° undepressed on admixture with an authentic specimen.

Oxidation of N-(3 : 4-*Dihydroxybenzyl*)-3 : 4-*dihydroxyphenethylamine.*—(a) *Gaseous oxygen.* Preliminary and preparative experiments were carried out in the manner described above. Oxygen uptake (4 atoms) was complete in 4 min. From *N*-3 : 4-dihydroxybenzyl-3 : 4-dihydroxyphenethylamine hydrochloride (0·5 g.), 1-(3 : 4-*dimethoxybenzyl*)-5 : 6-*dimethoxyindole* (0·25 g.) was obtained, which after two recrystallisations from methanol (charcoal) afforded prisms, m. p. 121—122° (Found : C, 69·4; H, 6·6; N, 4·1. $C_{19}H_{21}O_4N$ requires C, 69·7; H, 6·4; N, 4·3%). The indole gives a magenta colour with Ehrlich's reagent in the cold and slowly darkens when kept.

(b) *Potassium iodate.* A solution of potassium iodate (0·35 g.) in water (30 c.c.) was added to one of the hydrochloride (0·5 g.) in water (500 c.c.). After 30 min., the red solution was treated with aqueous sulphur dioxide (10 c.c.) and worked up, as previously described, to give 1-(3 : 4-dimethoxybenzyl)-5 : 6-dimethoxyindole (50 mg.), m. p. and mixed m. p. 121—122°.

(c) *Potassium ferricyanide.* The oxidation was carried out according to Harley-Mason's method.[4] The ethyl acetate extract of the tetrahydroxyindole was evaporated and the residue methylated with sodium hydroxide and dimethyl sulphate under hydrogen. Sublimation of the crude product at 120°/0·5 mm. gave 1-(3 : 4-dimethoxybenzyl)-5 : 6-dimethoxyindole, m. p. and mixed m. p. 120—121°.

3 : 4-*Dimethoxyaniline.*—4-Nitroveratrole was obtained by nitrating veratrole with concentrated nitric acid in acetic acid. Hydrogenation of the nitro-compound in alcohol, a Raney nickel catalyst being used at 80° and 75 atm. pressure for 15 min., gave 3 : 4-dimethoxyaniline as a colourless solid, b. p. 160°/14 mm., in almost quantitative yield.

3 : 4-*Dimethoxy*-N-(3 : 4-*methylenedioxybenzylidene*)*aniline.*—A solution of 3 : 4-dimethoxyaniline (43 g.) and piperonaldehyde (45·5 g.) in ethanol (200 c.c.) was heated under reflux for 30 min. On cooling, the solution deposited 3 : 4-*dimethoxy*-N-(3 : 4-*methylenedioxybenzylidene*)-*aniline* (75 g., 94%) which crystallised from ethanol in needles or plates, m. p. 109° (Found : C, 67·1; H, 5·2. $C_{16}H_{15}O_4N$ requires C, 67·4; H, 5·3%).

3 : 4-*Dimethoxy*-N-(3 : 4-*methylenedioxybenzyl*)*aniline.*—A solution of 3 : 4-dimethoxy-*N*-(3 : 4-methylenedioxybenzylidene)aniline (5 g.) in dioxan (30 c.c.) was hydrogenated at atmospheric pressure in presence of several grams of Raney nickel. When hydrogen uptake (420 c.c.) was complete (45 min.), the catalyst was removed, and most of the solvent was removed under reduced pressure. Addition of water to the residue gave 3 : 4-*dimethoxy*-N-(3 : 4-*methylenedioxybenzyl*)*aniline* (4·8 g.). Recrystallisation from ethanol afforded prisms, m. p. 96° (Found : C, 66·9; H, 6·0; N, 4·6. $C_{16}H_{17}O_4N$ requires C, 66·9; H, 5·9; N, 4·9%). The amine gives a transient red colour, changing to bluish-green, when treated in alcohol with a drop of dilute aqueous ferric chloride.

The *hydrochloride* crystallised from dilute hydrochloric acid or ethanol in plates, m. p. 196° (Found : C, 59·4; H, 5·8; Cl, 10·8. $C_{16}H_{17}O_4N$,HCl requires C, 59·4; H, 5·6; Cl, 11·0%).

3 : 4-*Dimethoxy*-N-(3 : 4-*methylenedioxybenzyl*)-N-*nitrosoaniline.*—A solution of sodium nitrite (3·5 g.) in water (20 c.c.) was added to a solution of 3 : 4-dimethoxy-*N*-(3 : 4-methylenedioxybenzyl)aniline (10 g.) in glacial acetic acid (200 c.c.) until excess of nitrous acid was present, as indicated by a sudden change in colour of the solution from dark green to orange red. Addition of water (2 vol.) precipitated 3 : 4-*dimethoxy*-N-(3 : 4-*methylenedioxybenzyl*)-N-*nitrosoaniline*, pale-yellow slender needles (10 g.) (from ethanol), m. p. 119° (Found : C, 60·7; H, 5·3; N, 8·9. $C_{16}H_{16}O_5N_2$ requires C, 60·8; H, 5·1; N, 8·9%).

5 : 6-*Dimethoxy*-1-(3 : 4-*methylenedioxybenzyl*)*indole*-2-*carboxylic Acid.*—A suspension of 3 : 4-dimethoxy-*N*-(3 : 4-methylenedioxybenzyl)-*N*-nitrosoaniline (2 g.) in acetic acid (4 c.c.)–dioxan (6 c.c.) was added at <10° to a vigorously stirred mixture of zinc dust (4 g.) in water (2 c.c.), cooled in ice (*ca.* 15 min.). Pyruvic acid (0·5 c.c.) and, after 1 min., 20% sulphuric acid (8 c.c.) were added to the filtrate. The resultant golden-yellow solution was heated at 50° for 5 min. On cooling, the solution deposited 5 : 6-*dimethoxy*-1-(3 : 4-*methylenedioxybenzyl*)*indole*-2-*carboxylic acid* (0·4—0·6 g.), which was purified through its sodium salt (charcoal). Two recrystallisations from methanol then afforded the acid in fine needles, m. p. 189° (Found : C, 64·0; H, 5·0; N, 4·0. $C_{19}H_{17}O_6N$ requires C, 64·2; H, 4·8; N, 4·0%). When warmed with Ehrlich's reagent the acid develops a magenta colour, which disappears on cooling.

The *methyl ester*, prepared from the acid in dioxan and ethereal diazomethane, crystallised from methanol in felted needles, m. p. 136° (Found: C, 65·2; H, 5·3. $C_{20}H_{19}O_6N$ requires C, 65·0; H, 5·2%).

5 : 6-*Dimethoxy*-1-(3 : 4-*methylenedioxybenzyl*)*indole*.—When 5 : 6-dimethoxy-1-(3 : 4-methylenedioxybenzyl)indole-2-carboxylic acid (0·5 g.) was heated 2—3° above its m. p., carbon dioxide was evolved. After 5 min., gas evolution had ceased, and the residue was dissolved in hot methanol. On cooling, the solution deposited a solid (0·3 g.), which on crystallisation from a small quantity of methanol afforded 5 : 6-*dimethoxy*-1-(3 : 4-*methylenedioxybenzyl*)*indole* in small needles, m. p. 93° (Found: C, 69·3; H, 5·6. $C_{18}H_{17}O_4N$ requires C, 69·5; H, 5·5%). The indole slowly darkens, and gives a magenta colour with Ehrlich's reagent in the cold.

N-(3 : 4-*Dimethoxybenzylidene*)-3 : 4-*dimethoxyaniline*.—A solution of 3 : 4-dimethoxyaniline (8·4 g.) and veratraldehyde (9·1 g.) in ethanol (25 c.c.) was heated under reflux for 30 min. The *Schiff's base*, which separated on cooling, crystallised from ethanol in small pale-yellow needles, m. p. 136° (Found: C, 67·6; H, 6·3. $C_{17}H_{19}O_4N$ requires C, 67·8; H, 6·3%).

N-(3 : 4-*Dimethoxybenzyl*)-3 : 4-*dimethoxyaniline*.—A solution of the Schiff's base (7·5 g.) in dioxan (25 c.c.) was shaken with Raney nickel under hydrogen (45 min.). After filtration, the solution was evaporated under reduced pressure. Addition of water to the residue and crystallisation (7 g.) from methanol gave needles, m. p. 93°. The amine soon turns yellow.

The *hydrochloride* formed feathery needles, m. p. 208°, from methanol (Found: C, 60·2; H, 6·9. $C_{17}H_{21}O_4N$,HCl requires C, 60·2; H, 6·8%). The *nitrosamine* was prepared in acetic acid, and formed pale-yellow irregular platelets (from methanol), m. p. 93° depressed on admixture with the original amine (Found: C, 61·4; H, 6·1; N, 8·1. $C_{17}H_{20}O_5N_2$ requires C, 61·5; H, 6·0; N, 8·4%).

1-(3 : 4-*Dimethoxybenzyl*)-5 : 6-*dimethoxyindole*.—*N*-(3 : 4-Dimethoxybenzyl)-3 : 4-dimethoxy-*N*-nitrosoaniline was reduced with zinc dust and acetic acid in the manner described for the *N*-(3 : 4-methylenedioxybenzyl) analogue. The hydrazine was treated with pyruvic acid, and the resultant hydrazone cyclised to the indolecarboxylic acid with dilute sulphuric acid, as described previously. The yield of the indole-2-carboxylic acid was very small. When heated at 180°/0·1 mm., it gave a sublimate of 1-(3 : 4-dimethoxybenzyl)-5 : 6-dimethoxyindole, m. p. 122° undepressed on admixture with the specimens obtained from the oxidation experiments.

The author thanks Professor Sir Robert Robinson, O.M., F.R.S., for his kindly interest and encouragement; also Fisons Limited, Ipswich, for generous financial assistance.

DYSON PERRINS LABORATORY, OXFORD. [*Received, September 1st*, 1955.]

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105. *Partial Reduction of Steroid Hormones and Related Substances. Part II.* A New Synthetic Route to Steroidal* 20 : 21-*Ketols.*

By J. K. NORYMBERSKI.

The 17-hydroxyl group is removed from 17α : 21-dihydroxy-20-oxo-steroids by zinc in aqueous acetic acid. The examples investigated include the conversion of cortisol into corticosterone.

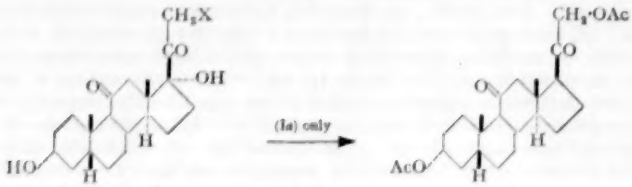
ALTHOUGH 11-oxygenated 17α : 21-dihydroxy-20-oxo-steroids have become readily available, their 17-deoxy-analogues are still difficult to obtain. The present work concerns the one-step conversion of compounds of the former into those of the latter class by a method capable of wide application.

Treatment of 3α : 17α : 21-trihydroxypregnane-11 : 20-dione (I*a*) with zinc in boiling aqueous acetic acid, followed by acetylation, gave 3α : 21-diacetoxypregnane-11 : 20-dione [1] (II) as the sole product. 21-Acetoxy-3α : 17α-dihydroxypregnane-11 : 20-dione (I*b*) and 3α : 17α-dihydroxypregnane-11 : 20-dione (I*c*) failed to react under identical conditions. Evidently the presence of a free 21-hydroxyl is necessary for the hydrogenolysis of the $C_{(17)}$–O bond, possibly because it facilitates the effective binding of the dihydroxyacetone (I*a*) on the zinc surface.

* Part I, *J.*, 1955, 3426.

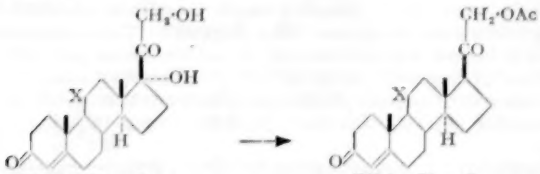
[1] Sarett, *J. Amer. Chem. Soc.*, 1948, **70**, 1454.

It appears [2] that 4 : 5-unsaturated 3-ketones are resistant towards zinc in acetic acid and hence it seemed feasible to use this reagent for the selective removal of the 17-hydroxyl from cortisone (III*a*) and from cortisol (III*b*). In fact, the two compounds gave severally 11-dehydrocorticosterone acetate [3] (IV*a*) and corticosterone acetate [3] (IV*b*), though in



(I*a*) : X = OH
(I*b*) : X = OAc
(I*c*) : X = H

(II)



(III*a*) : X = O
(III*b*) : X = OH (β)

(IV*a*) : X = O
(IV*b*) : X = OH (β)

both reactions some reduction of the 4-en-3-one grouping was indicated by ultraviolet spectroscopy. In many respects the above conversions compare favourably with the known preparative routes to 11-dehydrocorticosterone [4] and corticosterone.[4b, 5]

Experimental

Specimens for analyses were dried in a high vacuum for 4—16 hr. at 80—100°. M. p.s were determined on a Kofler stage. Unless otherwise specified, rotations were measured in $CHCl_3$ (at 15—20°), ultraviolet absorption spectra in EtOH. For chromatography neutralised alumina [6] was used; elution was effected with benzene of gradually increasing content of ethyl acetate. Acetylations were performed with acetic anhydride in pyridine at room temperature.

Treatment with Zinc. General Procedure.—A 0·02—0·03M-solution of the steroid in aqueous acetic acid (50%; v/v) was treated under reflux with 40—80 mol. of zinc dust ("AnalaR") for 60—90 min. The still hot solution was filtered and the zinc was washed with methanol. Ice was added to the filtrate and then enough 3N-sodium hydroxide to neutralise nine-tenths of the acetic acid. The mixture was extracted with ether–chloroform in the usual manner.

Treatment of 3α : 17α : 21-*Trihydroxypregnane*-11 : 20-*dione* (I*a*) *with Zinc.*—This compound (100 mg.) was treated by the general procedure, followed by acetylation and chromatography on alumina. 3α : 21-*Diacetoxypregnane*-11 : 20-*dione* (II) (88 mg., 74%) was eluted in the early fractions. Crystallisation from ether–light petroleum gave prisms (75 mg., 63%), m. p. 107—109°, $[\alpha]_D$ +127° (*c*, 2·15) (Found: C, 69·9; H, 8·15. $C_{25}H_{36}O_6$ requires C, 69·4; H, 8·4%). The compound was identified with authentic material by mixed m. p. and comparison of the infrared spectra.

[2] Fieser, *ibid.*, 1953, **75**, 4377; Amendolla, Rosenkranz, and Sondheimer, *J.*, 1954, 1226.
[3] Reichstein, *Helv. Chim. Acta*, 1937, **20**, 953.
[4] (*a*) Lardon and Reichstein, *ibid.*, 1943, **26**, 747; (*b*) von Euw, Lardon, and Reichstein, *ibid.*, 1944, **27**, 1287; (*c*) von Euw and Reichstein, *ibid.*, 1946, **29**, 1913; Sarett, *J. Amer. Chem. Soc.*, 1946, **68**, 2478; Wettstein and Meystre, *Helv. Chim. Acta*, 1947, **30**, 1262; von Euw and Reichstein, *ibid.*, 1948, **31**, 2076; Mattox and Kendall, *J. Biol. Chem.*, 1951, **188**, 287; Poos, Lukes, Arth, and Sarett, *J. Amer. Chem. Soc.*, 1954, **76**, 5031.
[5] Wendler, Huang-Minlon, and Tishler, *J. Amer. Chem. Soc.*, 1951, **73**, 3818; Lardon and Reichstein, *Helv. Chim. Acta*, 1954, **37**, 443; Taub, Pettebone, Wendler, and Tishler, *J. Amer. Chem. Soc.*, 1954, **76**, 4094; Bernstein and Lenhard, *ibid.*, 1955, **77**, 8331.
[6] Brooks and Norymberski, *Biochem. J.*, 1953, **55**, 371.

The authentic specimen was prepared by acetylation of 3α : 21-dihydroxypregnane-11 : 20-dione, kindly provided by Dr. W. Klyne from the M.R.C. Steroid Reference Collection. It had m. p. 107—109°, $[\alpha]_D$ +123° (*c*, 0·97) (Found : C, 68·9; H, 8·2. Calc. for $C_{25}H_{36}O_6$: C, 69·4; H, 8·4%). The compound has not been previously fully described. Sarett [1] reported m. p.s 100—110° and 82—90° for specimens crystallised from different solvents, in a patent [7] the m. p. 95—105° was recorded, and Colton and Kendall [8] gave m. p. 131°, $[\alpha]_D$ +127°.

Treatment of 21-*Acetoxy*-3α : 17α-*dihydroxypregnane*-11 : 20-*dione* (I*b*) *with Zinc.*—This compound (120 mg.) was treated as above. Crystallisation of the crude acetylated product first from methanol and then from acetone–hexane afforded pure 3α : 21-diacetoxy-17α-hydroxypregnane-11 : 20-dione (85 mg.) of m. p. and mixed m. p. 229—231°, $[\alpha]_D$ +112° (*c*, 1·31), +89° (*c*, 0·82 in acetone) (Found : C, 66·9; H, 8·2. Calc. for $C_{25}H_{36}O_7$: C, 66·9; H, 8·1%). Sarett [1] found m. p. 233—236°, $[\alpha]_D$ +93° (in acetone). The pronounced effect of solvent on the rotatory power of this compound is consistent with observations made on other 17 : 20-ketols.[9]

Treatment of 3α : 17α-*Dihydroxypregnane*-11 : 20-*dione* (I*c*) *with Zinc.*—This compound (100 mg.) was treated with zinc as above. Crystallisation from acetone–light petroleum gave starting material (70 mg.) of m. p. and mixed m. p. 200—202°, $[\alpha]_D$ +41° (*c*, 1·15), +63·5° (*c*, 1·12 in acetone). Sarett [1] reported m. p. 207—208°, $[\alpha]_D$ +68·5° (in acetone).

Treatment of Cortisol (III*b*) *with Zinc.*—Cortisol (300 mg.) was treated as above, and the crude acetylated product was chromatographed. An unidentified gum [100 mg.; $\lambda_{max.}$ 208 and 240 mμ ($E^{1\%}_{1cm.}$ 110 and 210)] was first eluted and was followed by corticosterone acetate (IV*b*) (160 mg., 50%). One crystallisation from acetone–hexane gave pure material (120 mg., 37%), m. p. 145—146° (solidifies on cooling and on re-heating melts at 152—153°), $[\alpha]_D$ +221° (*c*, 0·67), $\lambda_{max.}$ 241 mμ (ε 16,000) (Found : C, 70·9; H, 8·4. Calc. for $C_{23}H_{32}O_5$: C, 71·1; H, 8·3%). The compound was identified with authentic material {m. p.s 145—146° and 152—153°, $[\alpha]_D$ +220° (*c*, 1·05)} by mixed m. p. and comparison of infrared spectra. The physical constants found are in agreement with those recorded in the literature.[3,5]

Oxidation of the above product with chromic oxide [3] gave 11-dehydrocorticosterone acetate (IV*a*), m. p. 178—180°, $[\alpha]_D$ +247° (*c*, 0·78), $\lambda_{max.}$ 238 mμ (ε 17,000) (Found : C, 71·3; H, 8·0. Calc. for $C_{23}H_{30}O_5$: C, 71·5; H, 7·8%), in agreement with the properties recorded elsewhere.[3,4]

Treatment of Cortisone (III*a*) *with Zinc.*—Cortisone (250 mg) was treated as above. Chromatography of the crude acetylated product gave, first, gummy unidentified fractions (60 mg.) of which an earlier eluted part (20 mg.) had no specific absorption at or about 238 mμ. Crystalline 11-dehydrocorticosterone acetate (IV*a*) (95 mg., 35%) was next eluted. It gave prismatic needles (70 mg., 26%) (from acetone–hexane), m. p. 177—180° (undepressed on admixture with material obtained from oxidation of corticosterone acetate), $[\alpha]_D$ +242° (*c*, 0·57), $\lambda_{max.}$ 238 mμ (ε 18,000) (Found : C, 71·4; H, 8·0. Calc. for $C_{23}H_{30}O_5$: C, 71·5; H, 7·8%).

This work was done during the tenure of an Empire Rheumatism Council Research Fellowship. The author is much indebted to Dr. A. E. Kellie for infrared measurements and to Dr. W. Klyne for the facilities of the M.R.C. Steroid Reference Collection. Gifts of steroids from Messrs. Merck and Co., Inc. (Rahway), and from Messrs. I. V. Organon (Oss) are gratefully acknowledged.

Chemical Research Laboratory, Rheumatism Research Unit,
Nether Edge Hospital, Sheffield, 11. [*Received, September 14th*, 1955.]

[7] Swiss P. 274,689/1951; cf. *Chem. Abs.*, 1952, **46**, 4582.
[8] Colton and Kendall, *J. Biol. Chem.*, 1952, **194**, 247.
[9] Norymberski, *J.*, 1954, 762.

106. *Exchange Reactions and Magnetic Susceptibilities of Complex Salts. Part IV.* Correlation with Absorption Spectra.*

By H. C. Clark and A. L. Odell.

Absorption spectra in the visible and ultraviolet regions of six nickel chelate compounds in various solvents have been determined, and correlations with magnetic measurements are suggested.

In pyridine solutions of bis-salicylaldiminenickel and bis-salicylaldehyde-*o*-phenylenedi-iminenickel, and in alcohol and dioxan solutions of bis-*N*-methylsalicylaldiminenickel, the effects of temperature changes can be correlated with the previously reported magnetic susceptibilities which indicated the presence of temperature-dependent equilibria between diamagnetic and paramagnetic forms. Absorption spectra in other solvents are discussed.

Although detailed analysis of absorption spectra of complex compounds is not yet possible, several attempts have been made to relate these spectra to their stereochemistry. McKenzie, Mellor, Mills, and Short [1] found that many paramagnetic nickel complexes show the same absorption bands as the free ligands, while for the diamagnetic complexes there appears a new band at *ca.* 410 mμ. These spectra were investigated in solution, but, as the authors point out, most of the magnetic-susceptibility determinations were made on solid samples. Willis and Mellor [2] reported that many of these complexes show a change from diamagnetism to paramagnetism on entering solution, and it has also been shown [3] that in many instances the change is incomplete and dependent on temperature. It was therefore decided to re-investigate the absorption spectra of the compounds over a temperature range.

We followed the procedure of McKenzie *et al.*[1] in tabulating results as molecular extinction coefficients (ε) at the wavelength showing absorption maxima. Tables 1 and 2 refer

Table 1. *Absorption spectra of complex compounds in various solvents at* 20°.

Complex	Solvent [a]	λ_1	ε_1	λ_2	ε_2	λ_3	ε_3
Bis-salicylaldehydenickel dihydrate	MeOH	385	4900	—	—	—	—
	C_5H_5N	398	7000	—	—	—	—
Bis-salicylaldehyde-ethylenediiminenickel	MeOH	402	5800	325	8050	—	—
	C_5H_5N	414	6400	328	8320	—	—
Bis-salicylaldiminenickel	MeOH	402	4900	322	9580	—	—
	C_5H_5N	376	6460	324	6000	—	—
Bis-salicylaldoximenickel	EtOH	383	4850	302	17,500	—	—
	$CHCl_3$	388	5350	302	17,500	—	—
	C_5H_5N	355	7650	—	—	—	—
Bis-*N*-methylsalicylaldiminenickel	EtOH	355	5900	330	6100	—	—
	$C_4H_8O_2$	410	780	315	7050	—	—
	$CHCl_3$	414	3300	325	8200	—	—
	C_6H_6	413	3500	325	8550	—	—
	C_6H_5Me	414	3400	325	8400	—	—
	m-$C_6H_4Me_2$	414	3600	325	8800	—	—
	C_6H_{12}	416	3400	328	8500	—	—
	C_5H_5N	378	8300	—	—	—	—
Bis-salicylaldehyde-*o*-phenylenediiminenickel	MeOH	470	8750	372	26,800	300	18,150
	$CHCl_3$	478	8600	378	27,000	300	18,300
	C_5H_5N	445	19,000	384	18,000	—	—

[a] $C_4H_8O_2$ = dioxan; C_6H_{12} = *cyclo*hexane.

to measurements at 20°, and Table 3 refers to variation of maxima and to the appearance of new maxima as the temperature changes. From these Tables 1 and 2 it is clear that absorption in the region 350—450 mμ appears only when the metal ion and ligand unite to form the complex. Salicylaldehyde-ethylenedi-imine is an exception and shows a weak

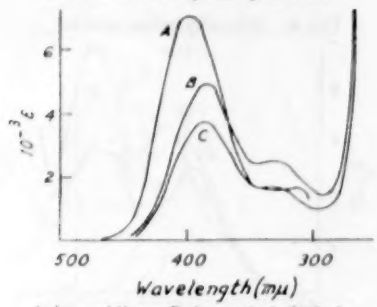
* Parts II and III, *J.*, 1955, **3431**, 3435.

[1] McKenzie, Mellor, Mills, and Short, *J. Proc. Roy. Soc. New South Wales*, 1944, **78**, 70.
[2] Willis and Mellor, *J. Amer. Chem. Soc.*, 1947, **69**, 1237.
[3] Clark and Odell, *J.*, 1955, **3431**.

absorption band at 403 mμ, which Csokan and Nyiri [4] have attributed to a hydrogen bond between the nitrogen and the oxygen atom in the *ortho*-position. It seems reasonable to conclude that the variations in intensities in the bands of this region of the spectrum are associated with changes in the mode of bonding of the metal atom rather than with changes in the structure of the ligand.

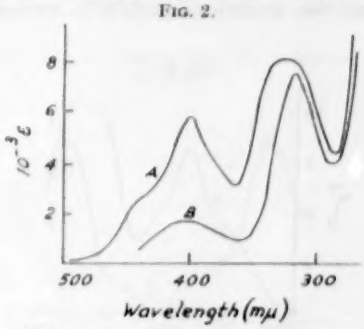
Temperature effects were observed for the solutions listed in Table 3. Other solutions showed variations with temperature only of the order of the experimental error.

FIG. 1. *Bis-salicylaldehydenickel.*



A, in pyridine; *B*, in methyl alcohol; *C*, in ethyl alcohol.

FIG. 2.



A, Bis-salicylaldehyde-ethylenedi-iminenickel in methyl alcohol.
B, Salicylaldehyde-ethylenedi-imine in methyl alcohol.

Bis-salicylaldehydenickel (Fig. 1) has a magnetic moment of 3·2 B.M. in the solid state, and 3·26 B.M. in pyridine solution. Basolo and Matoush [5] have isolated from the pyridine solutions a derivative containing two molecules of pyridine: it is probably an octahedral complex, and the marked similarity between the absorption spectra of the pyridine and the

TABLE 2. *Absorption spectra of ligands in various solvents at* 20°.

Ligand	Solvent	λ_1	ε_1	λ_2	ε_2
Salicylaldehyde-ethylenedi-imine	MeOH	403	1270	318	7000
	C_5H_5N	—	—	319	6800
Salicylaldehyde-*o*-phenylenedi-imine	MeOH	—	—	330	8700
	C_5H_5N	—	—	330	9000
Salicylaldoxime [a]	EtOH	305	4000	265	6300

[a] Sone, *J. Amer. Chem. Soc.*, 1953, **75**, 5207.

TABLE 3. *Effect of temperature on absorption spectra.*

Complex	Solvent	Positions of maxima (mμ)	ε 0°	ε 20°	ε 35°	ε 45°
Bis-salicylaldiminenickel	C_5H_5N	410	2860	3110	3410	3580
		375	7650	6450	5460	5130
		340	5350	5970	6400	6790
		322	5000	5900	6700	7250
Bis-*N*-methylsalicylaldimine-nickel	EtOH	410	1490	2130	2480	2580
		358	6500	6000	5380	5100
		330	5450	6050	6550	6620
Bis-*N*-methylsalicylaldimine-nickel	$C_4H_8O_2$	410	—	780	1160	1300
		360	—	2140	2140	1880
		315	—	7050	7150	7200
Bis-salicylaldehyde-*o*-phenylene-di-iminenickel	C_5H_5N	445	22,600	19,000	15,500	14,100
		384	14,900	17,850	20,200	22,000
		348	17,800	16,800	16,600	16,000

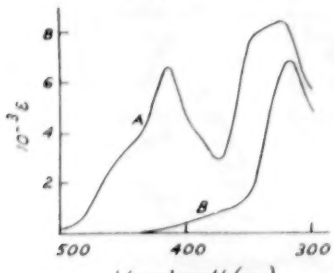
alcohol solutions leads one to suppose that two alcohol molecules also occupy co-ordination positions.

Bis-salicylaldehyde-ethylenedi-iminenickel (Figs. 2 and 3) shows the type of spectrum

[4] Csokan and Nyiri, *Magyar Chem. Folyóirat*, 1941, **47**, 149.
[5] Basolo and Matoush, *J. Amer. Chem. Soc.*, 1953, **75**, 5663.

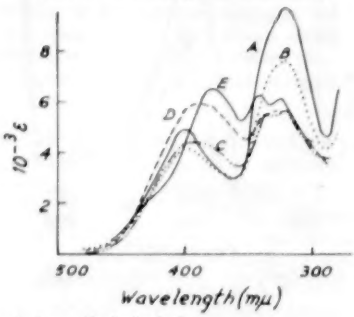
regarded by McKenzie *et al.*[1] as typical of diamagnetic nickel complexes, having an intense band at 402 mμ in methanol, and shifted to 414 mμ in pyridine. (This shift appears to be general for these nickel complexes in this solvent.) This complex is diamagnetic in the solid state and also in pyridine solution; it has a negligible rate of ligand exchange.[6] This behaviour may be explained[3] in terms of a dsp^2 planar configuration, or alternatively a d^2sp^3 disolvated octahedral structure involving the promotion of two electrons to a 5*s* orbital. The high energy increment involved in such a promotion renders the second explanation unlikely, especially in view of the weak co-ordinating properties of ethanol.

FIG. 3.



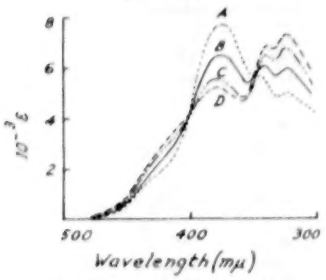
A, Bis-salicylaldehyde-ethylenedi-iminenickel in pyridine.
B, Salicylaldehyde-ethylenedi-imine in pyridine.

FIG. 4. *Bis-salicylaldiminenickel.*



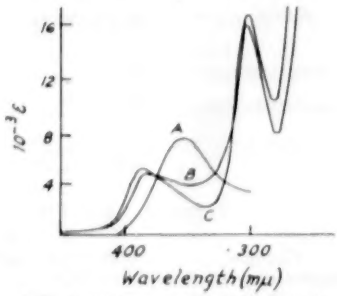
A, in methyl alcohol;
B, in 99% methyl alcohol–1% pyridine;
C, in 95% methyl alcohol–5% pyridine;
D, in 90% methyl alcohol–10% pyridine;
E, in pyridine.

FIG. 5. *Bis-salicylaldiminenickel in pyridine.*



A, at 0°; *C*, at 35°;
B, at 20°; *D*, at 45°.

FIG. 6. *Bis-salicylaldoximenickel.*



A, in pyridine; *B*, in ethyl alcohol;
C, in chloroform.

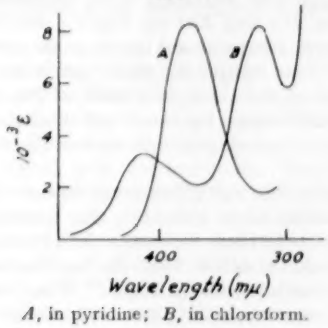
The similarity of the spectra in ethanol and in pyridine leads us to suppose that in each of these solvents the complex has a dsp^2 square configuration. In neither solvent was a change in magnetic moment or in absorption spectrum observed with changing temperature.

Bis-salicylaldiminenickel (Figs. 4 and 5) has in methanol solution an absorption spectrum of the form expected for a diamagnetic complex, although the magnetic susceptibility in this solvent could not be determined because of the low solubility. In Part II[3] it was shown that this compound in pyridine solution exhibits a temperature-dependent equilibrium between diamagnetic and paramagnetic forms, and it was suggested that the latter form was an octahedral bispyridine adduct. Absorption maxima were observed for the pyridine solution at 375, 343, and 324 mμ. A strong absorption at 322 mμ, with a pronounced "shoulder" in the 340 mμ region, was also observed in methanol

[6] Clark and Odell, *J.*, 1955, 3435.

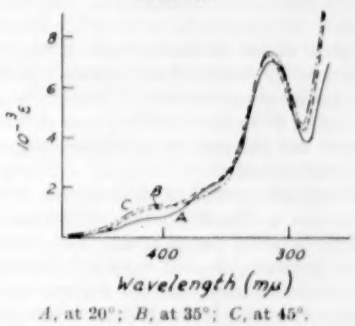
solution, in which the material is presumably diamagnetic. On the other hand, the 376 mμ band can reasonably be compared with the 378 mμ band observed in the absorption spectrum of bis-*N*-methylsalicylaldiminenickel in pyridine, where extreme paramagnetic behaviour is observed, which is ascribed to the presence of a bispyridine adduct. Curves in Fig. 4 show the rise of the 376 mμ peak, and the fall of the 342 and 324 mμ peaks, with increasing pyridine concentration in methanol solutions. On increase of temperature from 0° to 45°, the pyridine solution showed a decrease in the intensity of the 376 mμ band, and an increased absorption in the 400—415 mμ and 320—330 mμ regions (see Fig. 5).

FIG. 7. *Bis-N-methylsalicylaldiminenickel.*



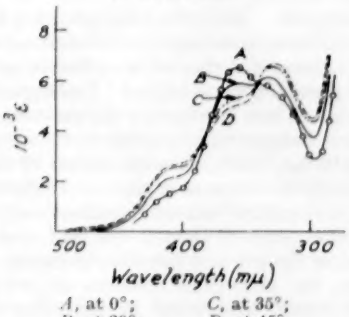
A, in pyridine; *B*, in chloroform.

FIG. 8. *Bis-N-methylsalicylaldiminenickel in dioxan.*



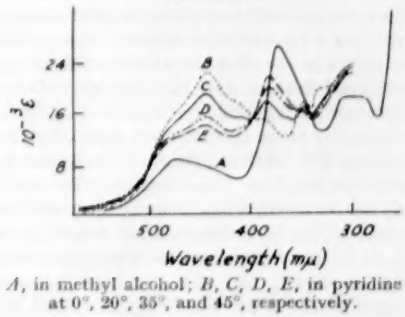
A, at 20°; *B*, at 35°; *C*, at 45°.

FIG. 9. *Bis-N-methylsalicylaldiminenickel in ethyl alcohol.*



A, at 0°; *C*, at 35°;
B, at 20°; *D*, at 45°.

FIG. 10. *Bis-salicylaldehyde-o-phenylenediiminenickel.*



A, in methyl alcohol; *B*, *C*, *D*, *E*, in pyridine at 0°, 20°, 35°, and 45°, respectively.

This change is in agreement with the presence of a temperature-dependent equilibrium favouring the diamagnetic form at higher temperatures.

Bis-salicylaldoximenickel (Fig. 6) in ethanol solution showed absorption maxima at 383 and 302 mμ, the former not being observed for an ethanol solution of the ligand. These results agree with those of Sone.[7] It seems reasonable to suppose that the band at 383 mμ is analogous to the "nickel" band observed in the 410 mμ region for diamagnetic complexes, the entire spectrum having been shifted some 20 mμ to shorter wavelengths. The spectrum of the chloroform solution of this complex is very similar to that of the ethanol solution. This was unexpected, in view of the magnetic moment of 1·7 B.M. found at 25° in chloroform,[3] which indicated a temperature-dependent equilibrium between paramagnetic and diamagnetic forms. The absorption spectra in both ethanol and chloroform showed no variation with temperature over the range 0—45°. In pyridine a single absorption maximum was observed at 355 mμ. With allowance for the shift of some 20 mμ (which

[7] Sone, *J. Amer. Chem. Soc.*, **1953**, **75**, 5207.

corresponds to 4·3 kcal./mole) observed with this complex in other solvents, this band may be compared with the 378 mμ band of the octahedral complexes. The isolation of a bispyridine adduct [3] of magnetic moment 3·2 B.M. supports this view.

Bis-*N*-methylsalicylaldiminenickel, although diamagnetic as a solid, was paramagnetic in all the solvents studied. In pyridine solution the formation of a bispyridine adduct has been established,[3] and the absorption spectrum of this solution (Fig. 7) shows only one band with a maximum at 378 mμ, suggesting again that this type of spectrum indicates octahedral configuration. In ethanol and dioxan solutions (Figs. 8 and 9), the observed magnetic susceptibilities indicate temperature-dependent equilibria. The spectra observed at 20° were different from those of typical diamagnetic complexes such as bis-salicylaldehyde-ethylenedi-iminenickel, and showed considerable variation with temperature. At higher temperatures, absorption increases in the 410 and 320 mμ regions, which are the typical bands of diamagnetic forms, while at lower temperatures these peaks become smaller and an intense band appears at 358 mμ. These results are thus correlated with the magnetic measurements. Similarity in the form of the absorption peak at 358 mμ in methanol at 0° to that at 378 mμ in pyridine (after allowance for the usual displacement to longer wavelengths in pyridine) suggests that the paramagnetic form is a disolvated octahedral adduct.

Absorption spectra of the complex in chloroform and in methylbenzenes do not fit into the pattern outlined above. Magnetic measurements have indicated the presence of equilibria between paramagnetic and diamagnetic forms in these solvents. The absorption spectra, however, showed typical " diamagnetic " bands at 415 and 325 mμ, and moreover, temperature changes caused no variation in intensity of these bands. Whether the paramagnetic form is octahedral or tetrahedral in these cases in not clear. Chloroform and the methylbenzenes are not likely to form strong bonds with the nickel atom, but the possibility of some solvation cannot be ruled out, as Rundle and Goring [8] have found evidence for a silver perchlorate–benzene complex.

Bis-salicylaldehyde-*o*-phenylenedi-iminenickel (Fig. 10). Magnetic measurements have shown that a temperature-dependent equilibrium between paramagnetic and diamagnetic forms exists in pyridine solutions of this complex. Absorption spectra in methanol and in chloroform solutions were identical and of the same general type as typical " diamagnetic " spectra, but with peaks at 470, 372—378, and 300 mμ. These bands were of high intensity. In comparing these spectra with those of other nickel complexes, it is convenient to regard the intense 372—378 mμ band as analogous to the 410 mμ " nickel " band, shifted 30 mμ to shorter wavelengths. This shift may be associated with the necessarily planar configuration of this ligand which would require *trans*-addition of the pyridine molecules. The absorption spectrum of the pyridine solution was different, and showed maxima at 442, 382, and 348 mμ. At higher temperatures, absorption increased in the 380 and the 470 mμ region, and decreased at 442 mμ; *i.e.*, at high temperatures, the absorption maxima occurred at approximately those wavelengths which showed strong absorption in the chloroform solution. This supports the observed increasing proportion of the diamagnetic form at higher temperatures.

The absorption spectra and magnetic susceptibilities of these complexes in solution can thus be correlated by using the postulate of an equilibrium between paramagnetic and diamagnetic forms in cases where the magnetic moments have intermediate values. Solutions in chloroform and hydrocarbon solvents do not, at present, fit this interpretation.

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Auckland University College, Auckland, New Zealand. [*Received, August 22nd*, 1955.]

[8] Rundle and Goring, *ibid.*, 1950, **72**, 5337.

107. *Equilibria between* cis- *and* trans-$[(MR_3)_2PtX_2]$ (*where* M = P, As, *and* Sb; X = *Halogen*).

By J. Chatt and R. G. Wilkins.

Equilibrium constants for the isomerisation *cis*-$[(MR_3)_2PtX_2] \rightleftharpoons$ *trans*-$[(MR_3)_2PtX_2]$ (R = hydrocarbon radical, X = halogen) have been estimated. The equilibrium shifts to the *trans*-side when chlorine is replaced by iodine, when phenyl groups are replaced by alkyl groups, when the homologous series is ascended from R = Me to R = Pr^n, and when the atoms, M, are changed in the order Sb, P, and As. The replacement of *n*-propyl by higher *n*-alkyl groups has little effect on the equilibrium.

In 1952 we reported [1] a detailed investigation of equilibria, in benzene solution, between *cis*- and *trans*-$[(MEt_3)_2PtCl_2]$ (M = P, As, and Sb). Attempts to extend this work to other alkyl derivatives proved difficult. The equilibrium for the higher homologues lies so far in favour of the *trans*-isomer that we could not determine its change with temperature sufficiently accurately to evaluate the heats and entropies of isomerisation; the trimethyl homologues were too insoluble. However, the position of equilibrium in benzene at 25° could be evaluated with fair accuracy, and here we shall record how the position of equilibrium changes as the hydrocarbon radical and halogens are changed.

The equilibria studied were of the type *cis*-$[(MR_3)_2PtX_2] \rightleftharpoons$ *trans*-$[(MR_3)_2PtX_2]$.

Lability of Simple Platinous Complexes $[(MR_3)_2PtCl_2]$.—The tri-*n*-alkylphosphine complexes, $[(PR_3)_2PtCl_2]$, are stable in solution at room temperature at least up to the tri-*n*-butyl derivative. The corresponding arsine complexes are labile, isomerising very slowly at room temperature; the qualitatively observed rate of isomerisation decreases slightly from R = Me to R = Pr^n, then increases again with R = Bu^n. The isomerisation can be prevented for long periods by the addition of a trace of a bridged complex $[(MR_3)_2Pt_2Cl_4]$ (M = P or As). The corresponding stibine complexes are much more labile and isomerisation cannot be prevented by addition of a bridged complex, although its rate is diminished considerably; so only the less soluble *cis*-isomers can be isolated in the stibine series.[2] In all cases equilibration of the complexes $[(MR_3)_2PtCl_2]$ was facilitated in the presence of a trace of the free ligand, MR_3, and the equilibrium constants were determined by using solutions containing a trace of MR_3.

Triphenyl compounds $[(MPh_3)_2PtCl_2]$ are too insoluble in benzene at 25° for the position of equilibrium to be measured. Only one isomer of each (M = P, As,* and Sb) was isolated and its colour and insolubility indicated that it was a *cis*-isomer. The effect of the phenyl group on the equilibrium was determined by studying the complexes of $AsBu_2Ph$. The iodo-platinous complexes are much more labile than their chloro-analogues.

Table 1. *Equilibrium constants (K) of the isomerisation* cis-$[L_2PtX_2] \rightleftharpoons$ trans-$[L_2PtX_2]$ *in benzene at* 25°.

L	PEt_3 *	PPr^n_3	PBu^n_3	PPe_3†	PPr^n_3	$AsMe_2Et$	$AsEt_3$ *
X	Cl	Cl	Cl	Cl	I	Cl	Cl
cis-Isomer in equilm. (%)	7·52	3·28	3·77	3·40	~0·55	1·8	0·57
K	12·3	29·5	25·5	28·4	~180	55	175
L	$AsPr^n_3$	$AsBu^n_3$	$AsBu^n_2Ph$	$SbEt_3$ *	$SbPr^n_3$	$SbBu^n_3$	$SbEt_3$
X	Cl	Cl	Cl	Cl	Cl	Cl	I
cis-Isomer in equilm. (%)	~0·15	~0·29	9·4	34·4	20	21	~I
K	~650	~340	9·6	1·9	4·0	3·75	~90

* The values for the triethyl series are taken from refs. 1 and 3 for comparison. † Pe = *n*-pentyl.

Influence of the Ligands on the Isomerisation Equilibrium.—The positions of equilibria were determined in benzene solution by measuring the dielectric constants of the solutions as described previously.[3] They are recorded in Table 1, and an estimate of the entropies

* *trans*-$[(AsPh_3)_2PtCl_2]$ is known (Jensen, *Z. anorg. Chem.*, 1936, **229**, 237.

[1] Chatt and Wilkins, *J.*, 1952, 4300.

[2] *Idem*, *J.*, 1953, 70.

[3] *Idem*, *J.*, 1952, 273.

and heats of isomerisation in the tri-*n*-propyl series of complexes is given in Table 2. These show the same pattern as the triethyl series.[1] In our first paper on this subject,[3] we suggested that the large entropy of isomerisation was due to unequal solvation of the two isomers, caused by their great difference in dipole moments. The equilibrium constant should therefore be very dependent on the polarisability of the solvent. A single experiment with carbon tetrachloride as solvent and *cis*-$[(SbPr^n_3)_2PtCl_2]$ as solute indicates that this is so. The value of K found was 14 as compared with 4 in benzene.

TABLE 2. *Free energies, heats, and entropies of isomerisation* cis- ⟶ trans- $[(MPr^n_3)_2PtCl_2]$ *in benzene at* 25°.

Substance	$-\Delta G$	ΔH	ΔS	Substance	$-\Delta G$	ΔH	ΔS	Substance	$-\Delta G$	ΔH	ΔS
$[(PPr^n_3)_2PtCl_2]$	2005	1975	13·3	$[(AsPr^n_3)_2PtCl_2]$	~3840	—	—	$[SbPr^n_3)_2PtCl_2]$	818	2200	10·1

The ligands, L, are all of the type, MR_2R', and we shall consider in turn the effect of changing M, the hydrocarbon radicals, and X on the position of equilibrium.

Influence of M *on the Equilibrium.*—The percentage of *cis*-isomer in the equilibrium mixtures of *cis*- and *trans*-$[(MR_3)_2PtCl_2]$ increases in the order M = As < P < Sb. The difference between the arsenic and phosphorus series is largely due to a change in the heat of isomerisation, but that between the phosphorus and antimony series to a change in the entropy of isomerisation. The possible causes and significance of these changes have been discussed in the light of a detailed analysis of equilibria in the triethyl series of complexes.[1]

Influence of Hydrocarbon Radicals R *and* R′ *on the Equilibrium.*—The equilibrium lies increasingly in favour of the *trans*-isomer as the homologous series is ascended from R = R′ = Me to R = R′ = Pr^n, but the equilibrium constant changes only slightly from R = R′ = Pr^n to R = R′ = *n*-pentyl. For reasons to be discussed later it is difficult to assess the reliability of the values in Table 2, but comparison with the corresponding data for the ethyl series indicates that the shift in equilibrium with change in alkyl radical is due very largely to a change in the heat of isomerisation. The stabilisation of the *trans*- relative to the *cis*-isomer is probably mainly steric in origin, because it is known that the difference between the electronic effects of the alkyl groups in such complexes is small.[4] The recession in the values of the equilibrium constant at R = R′ = Bu^n is probably significant since it was found in the phosphine, arsine, and stibine series. The replacement of a butyl group by a phenyl group shifts the equilibrium markedly to the *cis*-side (cf. the $AsBu^n_3$ and $AsBu^n_2Ph$ complexes). This shift may be partly steric in origin since the rigid phenyl group occupies less space in the immediate neighbourhood of the atom, M, than an alkyl group, but it may also be caused by electronic effects. The greater electronegativity of the phenyl group as compared with an alkyl group should increase the strength of the π-type bond between the atom, M, and the platinum atom, and hence the stability of the *cis*-isomer relative to the *trans*-isomer.[5]

Influence of the Halogen on the Equilibrium.—The replacement of chlorine by iodine causes a large shift of the equilibrium towards the *trans*-side. The stabilisation of the *cis*-isomers in the chloro-series of complexes has been attributed to the rather high double-bonding tendencies of the atom, M, as compared with chlorine.[1,3] It seems probable from its position in the *trans*-effect series that iodine has a much greater tendency than chlorine to form double bonds to platinum.[6] The shift of the equilibrium towards the *trans*-side, when chlorine is replaced by iodine, is probably caused, therefore, by the closer double-bonding tendencies of iodine and the atoms, M.

No *trans*-isomers of the type $[(SbR_3)_2PtX_2]$ are known in the solid state. Since the equilibrium between *cis*- and *trans*-$[(SbEt_3)_2PtI_2]$ lies much further to the *trans*-side than any other equilibrium in the stibine series, it was of interest to see whether we could isolate *trans*-$[(SbEt_3)_2PtI_2]$. As normally prepared, $[(SbEt_3)_2PtI_2]$ is a yellow solid which melts to a red liquid and gives red solutions in organic solvents. The red benzene solution we now know (Table 1) contains about 99% of the complex as its *trans*-isomer, and so we conclude

[4] Chatt, Duncanson, and Venanzi, *J.*, 1955, 4461.
[5] Chatt and Williams, *J.*, 1951, 3061.
[6] Chatt, Duncanson, and Venanzi, *J.*, 1955, 4456, and previous references quoted therein.

that the yellow solid is the *cis*-isomer. These colours are to be expected from our general knowledge of the colours of platinous complexes. When the benzene solution, containing a trace of a bridged complex to suppress so far as possible the lability of the equilibrium, was evaporated at 15 mm. a red oil remained. This changed into a red solid, presumably

TABLE 3. *Experimental quantities measured to determine the equilibrium constants, K, in benzene solution at 25°.*

Temp. (°K)	h_c	h_t	W (mg.)	W_L (mg.)	ΔC-k_L, W_L ($\mu\mu$F)	W_c (mg.)	W_t (mg.)	K
Isomerisation of *trans*-$(PPr_3)_2PtCl_2$								
292·86	22·8	0·261	980·3	3·0	1·027	34·2	946·1	27·65
			1359·6	4·0	1·430	47·7	1311·9	27·5
			595·9	3·0	0·578	19·5	576·4	29·55
298·15	22·1	0·254	802·5	3·0	0·772	25·9	776·6	29·9
			802·6	3·0	0·785	26·5	776·1	29·3
			1391·9	4·0	1·356	45·6	1346·3	29·55
			749·4	3·0	0·699	23·5	725·9	30·85
303·15	21·8	0·258	1006·2	3·0	0·940	31·6	974·6	30·8
			1205·0	3·0	1·126	37·8	1167·2	30·85
			402·4	2·0	0·353	11·7	390·7	33·4
308·15	20·3	0·297	604·0	2·0	0·541	18·1	585·9	32·4
			804·8	2·0	0·720	24·0	780·8	32·5
			1615·4	3·0	1·450	48·4	1567·0	32·4
Isomerisation of *cis*-$(PBu_3)_2PtCl_2$								
298·25	19·8	0·234	789·7	5·0	0·782	30·5	759·2	24·9
			994·6	5·0	0·983	38·3	956·3	25·0
Isomerisation of *trans*-$(PBu_3)_2PtCl_2$								
298·25	19·8	0·234	796·6	5·0	0·762	29·4	767·2	26·1
			959·7	5·0	0·931	36·1	923·6	25·6
Isomerisation of *cis*-$(PPe_3)_2PtCl_2$								
298·27	17·4	0·21 *	990·9	5·0	0·788	33·7	957·2	28·4
Isomerisation of *cis*-$(PPr_3)_2PtI_2$								
298·18	18·8	0·278	606·8	2·0	0·234	3·51	603·3	172
			755·4	2·0	0·330	6·48	748·9	116
Isomerisation of *trans*-$(PPr_3)_2PtI_2$								
298·15	18·8	0·278	607·0	2·0	0·225	3·02	604·0	200
			902·0	2·0	0·327	4·10	897·9	219
Isomerisation of *cis*-$(AsMe_2Et)_2PtCl_2$								
298·25	25·0 *	0·442	900·6	2·0 †	0·832	17·7	882·9	49·9
Isomerisation of *trans*-$(AsMe_2Et)_2PtCl_2$								
298·25	25·0 *	0·442	708·2	2·0	0·600	11·7	696·5	59·5
			796·8	2·0	0·690	13·8	783·0	56·8
			899·3	2·0	0·815	16·8	882·5	52·5
Isomerisation of *cis*-$(AsPr_3)_2PtCl_2$								
288·85	20·0	0·293	913·0	3·0	0·313	2·28	910·7	399
298·22	19·6	0·290	979·6	3·0	0·350	3·42	976·2	286
			1730·7	3·0	0·571	3·58	1727·1	482
			2005·9	3·0	0·742	8·29	1997·6	241
Isomerisation of *trans*-$(AsPr_3)_2PtCl_2$								
288·85	20·0	0·293	1501·1	3·0	0·485	2·28	1498·8	658
			1783·7	3·0	0·578	2·79	1780·9	638
			1993·9	3·0	0·633	2·49	1991·4	800
298·22	19·6	0·290	993·2	3·0	0·330	2·18	991·0	455
			1502·5	3·0	0·468	1·66	1500·8	904
Isomerisation of *trans*-$(AsBu_3)_2PtCl_2$								
298·15	17·4 *	0·248	1596·1	4·5	0·478	4·78	1591·3	333
			1996·9	4·5	0·591	5·60	1991·3	355
Isomerisation of *cis*-$(AsBu_2Ph)_2PtCl_2$								
298·35	17·4	0·25 *	493·6	7·0 ‡	0·950	48·3	445·3	9·2

TABLE 3. (*Continued.*)

Temp. (°K)	k_a	k_t	W (mg.)	W_L (mg.)	ΔC-k_L, W_L ($\mu\mu$F)	W_c (mg.)	W_t (mg.)	K
Isomerisation of *trans*-$(AsBu_2^tPh)_2PtCl_2$								
298·35	17·4	0·25 *	342·2	7·0 ‡	0·634	32·0	320·2	10·0
Isomerisation of *cis*-$(SbPr_3)_2PtCl_2$								
292·56	16·9	0·33 *	189·4	1·0	0·730	40·3	149·1	3·70
			199·1	2·0	0·769	42·4	156·7	3·70
			288·5	1·0	1·126	62·1	226·4	3·65
			368·3	2·0	1·416	78·0	290·3	3·72
298·01	16·75	0·33 *	212·1	2·0	0·769	41·2	170·9	4·15
			397·1	2·0	1·449	80·3	316·8	3·94
			514·2	2·0	1·874	103·7	410·5	3·96
			600·6	4·0	2·235	123·9	476·7	3·85
303·13	16·8	0·33 *	292·5	2·0	1·007	55·1	237·4	4·30
			392·0	3·0	1·352	74·2	317·8	4·28
			500·0	3·0	1·726	94·7	405·3	4·28
308·15	16·7	0·33 *	211·5	2·0	0·703	38·6	172·9	4·48
			303·3	2·0	1·003	55·1	248·2	4·51
298·35 §	16·45	0·33 *	399·7	1·0	0·561	26·6	373·1	14·0
Isomerisation of *cis*-$(SbBu_3)_2PtCl_2$								
298·36	15·15	0·27 *	193·2	1·0	0·660	40·8	152·4	3·74
			200·1	1·0	0·683	42·3	157·8	3·73
			249·4	—	0·858	53·2	196·2	3·69
			255·9	1·0	0·858	53·0	202·9	3·83
Isomerisation of *cis*-$(SbEt_3)_2PtI_2$								
298·33	15·0	0·27 *	346·2	‖	0·148	~3·7	~342·5	~92·5

* Estimated by extrapolation of k along the homologous or eutropic series. † With $AsEt_3$ as the catalyst, L. ‡ With $AsBu^t_3$ as the catalyst, L. § Carried out in carbon tetrachloride. ‖ Spontaneous isomerisation.

trans-$[(SbEt_3)_2PtI_2]$, but the solid reverted to the original yellow *cis*-$[(SbEt_3)_2PtI_2]$ during about 15 min.

Throughout these investigations, the equilibrium mixture obtained from the isomerisation of the *cis*-isomers was not exactly the same as that obtained by isomerising the *trans*-isomers. The difference was negligible in the isomerisation of the triethyl complexes and most marked in the tri-*n*-propylphosphine complexes. We were not able to discover its exact cause, which appears to be associated only with the *cis*-isomer. Isomerisation of different preparations of *trans*-$[(PPr^n_3)_2PtCl_2]$ always gave the same equilibrium constant, $K = 29·5 \pm 0·2$ at 25°, but isomerisation of different preparations of the *cis*-isomer gave values ranging from 15 to 28. The equilibrium "constants" obtained by isomerising any particular preparation of *cis*-$[(PPr^n_3)_2PtCl_2]$ were consistent within experimental error (about $\pm 0·2$) and usually had a value of about 20 at 25°, but when that preparation was recrystallised the "constant" would apparently change. The various preparations had correct melting points and analyses. The apparent change in equilibrium "constant" with repeated recrystallisation was not consistent: sometimes it would rise and at other times fall. The observed "constant" did not approach a definite value on repeated recrystallisation of the *cis*-$[(PPr^n_3)_2PtCl_2]$ or any other purification procedure which we tried. The "constant" did not depend on the quantity of tri-*n*-propylphosphine used to labilise the equilibrium. Since the isomerisation of *trans*-$[(PPr^n_3)_2PtCl_2]$ gave a definite value for the equilibrium constant we accepted it as most likely to be correct and the values given in Table 2 are based on that assumption.

EXPERIMENTAL

Microanalyses are by Messrs. W. Brown and A. G. Olney, of these laboratories.

Most of the platinous complexes in this investigation were prepared as precipitates by shaking a suspension of the organic ligand (*e.g.*, triethylphosphine) in an aqueous solution of

potassium chloroplatinite until reaction was complete. Except for those detailed below they are described by Jensen.[7]

cis-*Bistri*-n-*pentylphosphinedichloroplatinum*.—An ethanolic solution of sodium chloroplatinate and the phosphine (3 mols.) was boiled under reflux until the orange solution had become pale yellow (45 min.). This solution on cooling deposited white crystals of the *complex* which, recrystallised from ethanol, had m. p. 124—125° (Found: C, 47·9; H, 9·0. $C_{30}H_{66}Cl_2P_2Pt$ requires C, 47·7; H, 8·8%).

cis- *and* trans-*Bisethyldimethylarsinedichloroplatinum*.—A di-*n*-butyl ether solution of the arsine, shaken with aqueous potassium chloroplatinite, gave a brown precipitate of $[(AsMe_2Et)_4Pt][PtCl_4]$. This was removed, dried, and then decomposed by boiling its ethanol suspension until it had dissolved. When the solution was cooled, the very pale yellow cis-*isomer* separated and was recrystallised from ethanol; it had m. p. 177—178° (Found: C, 18·1; H, 4·1. $C_8H_{22}Cl_2As_2Pt$ requires C, 18·0; H, 4·1%). A portion of the product was converted into the yellow trans-*isomer* as described for its tri-*n*-propyl analogue,[8] and recrystallised from ether–acetone by cooling to −70°, then having m. p. 173—174° (Found: C, 18·1; H, 4·1%).

cis- and *trans*-Bisdibutylphenylarsinedichloroplatinum were prepared by the general method. The white cis-*isomer*, recrystallised from methanol, had m. p. 120—121° (Found: C, 41·9; H, 5·9. $C_{28}H_{46}Cl_2As_2Pt$ requires C, 42·0; H, 6·0%). The very soluble yellow *trans*-isomer, recrystallised from methanol by cooling to −70°, had m. p. 40—41°. This material still retained a trace of its *cis*-isomer as was evident from the slightly high dielectric constant of its benzene solutions. It was sufficiently pure for the isomerisation experiments.

trans-*Bistri*-n-*propylphosphinedi-iodoplatinum* was obtained by shaking the phosphine with aqueous potassium chloroplatinite (½ mol.) to which had been added potassium iodide (1½ mol.). Recrystallised from ethanol, it was obtained in chrome yellow crystals, m. p. 118—119° (Found: C, 28·3; H, 5·6. $C_{18}H_{42}I_2P_2Pt$ requires C, 28·1; H, 5·5%). The *cis*-isomer was obtained by mixing cold solutions of *cis*-$[(PPr^n_3)_2PtCl_2]$ in acetone (50 c.c.) and of potassium iodide in acetone–ethanol (100 c.c. of 1 : 1). The solution immediately changed from colourless to yellow and potassium chloride separated. The mixture was evaporated to dryness at 15 mm., and the residue extracted with water, then recrystallised from ethanol. The product was a mixture of *cis*- and *trans*-isomers which were separated by extracting the latter with light petroleum (b. p. 60—80°), leaving the cis-*isomer* (2·2 g.). It was converted into its *trans*-isomer on heating, and melted sharply in the range 119—125° (Found: C, 28·1; H, 5·5%).

Bistriethylstibinedi-iodoplatinum, prepared as described by Jensen,[7] is a yellow solid, m. p. 69° (Found: C, 16·6; H, 3·6. Calc. for $C_{12}H_{30}I_2PtSb$: C, 16·6; H, 3·4%). This material, on evaporation of its benzene solution as described on p. 527, gave a red solid which reverted to the yellow form in 15—20 min.

Determination of Equilibrium Constants.—The method whereby the constants were determined, and the meanings of the symbols used in Table 3, are as described by Chatt and Wilkins,[1,3] except that W_L = the weight of phosphine or arsine used to catalyse the isomerisation, and replaces the symbols W_p and W_a which were used in the previous publications.

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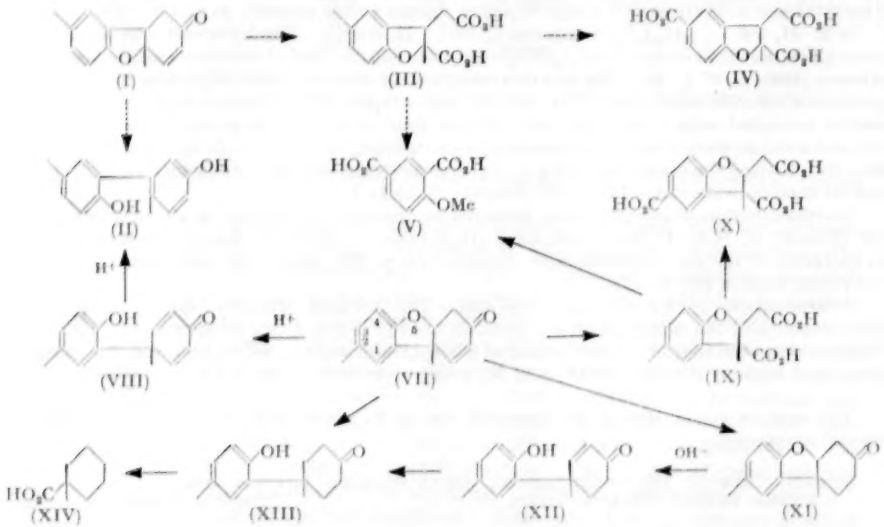
[7] Jensen, *Z. anorg. Chem.*, 1936, **229**, 237.
[8] Chatt and Wilkins, *J.*, 1951, 2532.

108. *The Synthesis of Usnic Acid.*

By D. H. R. Barton, A. M. Deflorin, and O. E. Edwards.

The constitution of the neutral crystalline dimer obtained by oxidation of *p*-cresol has been determined. The biogenetic significance of this compound has been illustrated by a simple two-step synthesis of (±)-usnic acid. The more important features of this work have already been summarised in preliminary form.[1]

The oxidation of phenols has received much attention.[2] Our interest in this subject was first stimulated by a disbelief in the structure (I) advanced by Pummerer, Puttfarcken, and Schopflocher [3] for the neutral crystalline dimer, m. p. 124°, obtained by oxidation of *p*-cresol by one-electron-transfer oxidising agents.[4] Although the constitution (I) appears to have been generally accepted, it is based on ambiguous evidence. Pummerer, Puttfarcken, and Schopflocher [3] showed that, on treatment with acid, the dimer gave 2 : 5′-dihydroxy-5 : 2′-dimethyldiphenyl ("2 : 3′-dicresol") (II). Westerfeld and Lowe [5] oxidised the compound with potassium permanganate to a dicarboxylic acid $C_{13}H_{14}O_5$, formulated as (III), which was further transformed by the same reagent into a tricarboxylic acid, $C_{13}H_{12}O_7$, regarded as (IV). Fusion of the acid $C_{13}H_{14}O_5$ with potassium hydroxide, methylation, and further permanganate oxidation gave 4-methoxy*iso*phthalic acid (V).



Now oxidative dimerisations of phenols of the type under discussion can be regarded as *either* the pairing of radicals *or* the substitution of one radical into a neutral phenol molecule

[1] Barton, Deflorin, and Edwards, *Chem. and Ind.*, 1955, 1039.

[2] For leading references see, for example, (*a*) Erdtman, *Annalen*, 1933, **503**, 283; *Svensk kem. Tidskr.*, 1934, **46**, 226; Haworth, *J.*, 1942, 455; (*b*) Critchlow, Haworth, and Pauson, *J.*, 1951, 1318; Waters and Wickham-Jones, *J.*, 1952, 2420; Witkop and Goodwin, *Experientia*, 1952, **8**, 377; Pummerer, Schmidutz, and Seifert, *Chem. Ber.*, 1952, **85**, 535; Freudenberg and Schraube, *ibid.*, 1955, **88**, 16; C. D. Cook, Nash, and Flanagan, *J. Amer. Chem. Soc.*, 1955, **77**, 1783; Harington, *J.*, 1944, 193; Pitt-Rivers, *Biochem. J.*, 1948, **43**, 223.

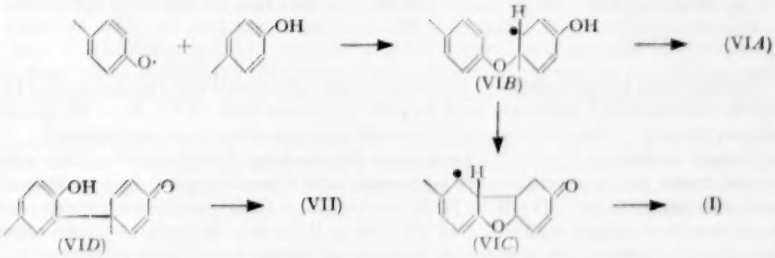
[3] Pummerer, Puttfarcken, and Schopflocher, *Ber.*, 1925, **58**, 1808.

[4] For leading references see : Pummerer, Melamed, and Puttfarcken, *Ber.*, 1922, **55**, 3116; Bowden and Reece, *J.*, 1950, 2249; Cosgrove and Waters, *J.*, 1951, 1726; Cavill, Cole, Gilham, and McHugh, *J.*, 1954, 2785.

[5] Westerfeld and Lowe, *J. Biol. Chem.*, 1942, **145**, 463.

followed by further oxidation. Pummerer *et al.*,[2,3] Schöpf,[6] and others [7] have regarded the formation of the dimer (I) as proceeding through an intermediate (VI*A*). It seemed to us, however, that the change from (VI*A*) to (I) was improbable. A second scheme for the formation of structure (I) involves radical substitution using radicals (VI*B*) and (VI*C*) as intermediates. In so far as radical (VI*B*) is the same type of hemiquinone radical that is encountered in the oxidation of quinols and catechols, it seemed to us that its probable

fate would be oxidation to (VI*A*) rather than cyclisation to (VI*C*). On these grounds we were encouraged to search for an alternative scheme for the dimerisation. If C–C coupling, either by pairing or by substitution, is the first step in the reaction, the first non-radical



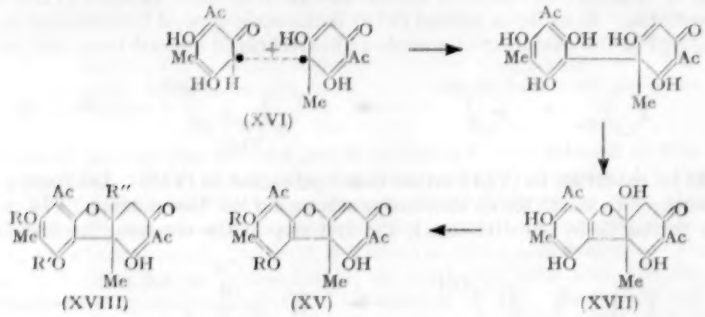
product would be (VI*D*). β-Addition of the phenolic hydroxyl to the enone system would then afford the product (VII). Such a scheme would avoid the theoretical difficulties referred to above.

The structure (VII) provides in every way a satisfactory formulation for the dimer, m. p. 124°, of *p*-cresol. Thus by dienone–phenol rearrangement (see VIII) the formation of (II) would be unexceptional. The $C_{13}H_{14}O_5$ acid (see above) becomes (IX), a formula which explains equally as well as (III) the formation of a tricarboxylic acid [now formulated as (X)] and of (V). The correctness of formulation (VII) was confirmed as follows. Hydrogenation of the dimer in ethyl acetate over palladised calcium carbonate gave a dihydro-derivative (XI). This showed the ultraviolet absorption spectrum of an aromatic ether and gave infrared maxima (in CS_2 solution) at 1722 (*cyclo*hexanone), 1210 (aromatic ether), and 862 and 807 cm.$^{-1}$ (1 : 2 : 4-trisubstituted benzene) consistent with its formulation. The ketone (XI) resisted further hydrogenation in neutral medium, but readily took up a second mol. of hydrogen in ethanolic sodium ethoxide over palladised charcoal [hydrogenation of (XII)] to give the keto-phenol (XIII). This showed an infrared maximum at 1712 cm.$^{-1}$ (*cyclo*hexanone; CS_2 solution); it also gave bands at 3300 (phenolic OH), 3100, 1614, 1520, 890, 822 (1 : 2 : 4-trisubstituted benzene), and 1688 (*cyclo*hexanone) cm.$^{-1}$ (all in Nujol). The keto-phenol was conveniently obtained in one step by the similar hydrogenation of the dimer (VII). Wolff–Kishner reduction of the keto-phenol (XIII) and oxidation of the product with potassium permanganate gave 1-methyl*cyclo*hexane-1-carboxylic acid (XIV).

In agreement with others,[2a] we believe that the oxidative pairing (or equivalent substitution process) of phenolic radicals is of some biogenetic importance. We illustrate the particular significance of the dimer (VII) in biogenetic concepts by a simple synthesis of (±)-usnic acid (XV; R = H).[8] Oxidation of methylphloracetophenone [see (XVI)]

[6] Schöpf, *Naturwiss.*, 1952, **39**, 241.
[7] See Bentley, "The Chemistry of the Morphine Alkaloids," Oxford University Press, 1954, p. 394 *et seq.*
[8] Curd and Robertson, *J.*, 1937, 894; see also: (*a*) Schöpf and Ross, *Annalen*, 1941, **546**, 1; (*b*) Barton and Bruun, *J.*, 1953, 603; (*c*) Asahina and Shibata, "The Chemistry of Lichen Substances," Japan Society for the Promotion of Science, Tokyo, Japan, 1954.

with potassium ferricyanide, as in the formation of (VII), gave as main crystalline product (15%) the expected dimer (XVII). Acetylation of this with acetic anhydride containing a trace of sulphuric acid gave a reasonable yield of (±)-usnic acid diacetate (XV; R = Ac),



further characterised by hydrolysis to (±)-usnic acid. Alternatively the dimer (XVII) was dissolved in concentrated sulphuric acid to give (±)-usnic acid (XV; R = H) directly in a two-step synthesis. The resolution of (±)-usnic acid has already been reported.[9]

Compounds analogous to (XVII) have been obtained by Takahashi.[10] Thus addition of methanol under acidic conditions to (±)-usnic acid diacetate gave (±)-usnic acid *iso*methoxide monoacetate (XVIII; R = H, R′ = Ac, R″ = OMe), which we have hydrolysed to (±)-usnic acid "*iso*methoxide" (XVIII; R = R′ = H; R″ = OMe). It would be expected that the ultraviolet absorption spectra of dihydrousnic acid (XVIII; R = R′ = R″ = H),[11] of the dimer (XVII), and of the "*iso*methoxide" (XVIII; R = R′ = H, R″ = OMe) would be superimposable. This is indeed the case, although our spectral data are not in agreement with those recorded by Takahashi.[10]

The revised structure (VII) for the *p*-cresol dimer has a direct bearing [6, 7] on the biogenesis of morphine alkaloids [12] which we are currently exploring.

Experimental

Ultraviolet absorption spectra were taken in EtOH solution using the Unicam S.P. 500 Spectrophotometer. Infrared absorption spectra were kindly determined by Messrs. Glaxo Laboratories Ltd.

Hydrogenation of the Ketone (VII).—The ketone (Pummerer *et al.*[3]) (645 mg.) was hydrogenated in ethyl acetate over 1% palladised calcium carbonate (400 mg.). One mol. of hydrogen was consumed within 15 min.; there was no further uptake. After removal of the catalyst by filtration, the solvent was removed *in vacuo* and the residue recrystallised from light petroleum (b. p. 40—60°) to give 1 : 2 : 3 : 4 : 4*a* : 9*b*-*hexahydro*-8 : 9*b*-*dimethyl*-3-*oxodibenzofuran* (numbering: Ring Index No. 1719) (XI) (500 mg.), m. p. (prisms) 81—82°, $\lambda_{max.}$ 287 mμ (ε 3500) (Found: C, 77·65; H, 7·55. $C_{14}H_{16}O_3$ requires C, 77·75; H, 7·45%).

Preparation of the Keto-phenol (XIII).—(i) *From the ketone* (VII). The ketone (4·3 g.) in dry ethanol (150 ml.) containing dissolved sodium (4·6 g.) was hydrogenated over 10% palladised charcoal. Two mols. of hydrogen were rapidly consumed; there was no further uptake. The catalyst was removed by filtration and the alkaline solution diluted with 5% aqueous hydrochloric acid (500 ml.). Extraction with ether, removal of the ether *in vacuo*, and crystallisation of the residue from aqueous ethanol gave the (2-*hydroxy*-5-*methylphenyl*)-4-*methyl*-4-*cyclohexanone* (XIII), m. p. 175—176° (Found: C, 77·3; H, 8·2. $C_{14}H_{18}O_2$ requires C, 77·05; H, 8·3%).

(ii) *From the dihydro-ketone* (XI). The dihydro-ketone (645 mg.) was hydrogenated in

[9] Dean, Halewood, Mongkolsuk, Robertson, and Whalley, *J.*, 1953, 1250.
[10] Takahashi, *Pharm. Bull.* (*Japan*), 1953, **1**, 36; for correct formulation see Asahina and Shibata, ref. 8*c*.
[11] For spectra see MacKenzie, *J. Amer. Chem. Soc.*, 1952, **74**, 4067; Barton and Bruun, ref. 8*b*.
[12] Robinson and Sugasawa, *J.*, 1931, 3163; 1932, 789; 1933, 280; 1936, 1079; (Sir) Robert Robinson, "The Structural Relations of Natural Products," Oxford University Press, 1955.

ethanolic sodium ethoxide as above. One mol. of hydrogen was rapidly absorbed. Crystallisation of the product as above gave the same keto-phenol (m. p. and mixed m. p.).

Conversion of the Keto-phenol (XIII) *into* 1-*Methylcyclohexane*-1-*carboxylic Acid* (XIV).—The keto-phenol (3·0 g.) was heated at 200° for 1 hr. with hydrazine hydrate (100%; 8 ml.) in diethylene glycol (300 ml.). Sodium (10 g.) in diethylene glycol (120 ml.) was then added and the solution refluxed for 6 hr. The cooled solution was diluted with aqueous 5% hydrochloric acid (500 ml.) and extracted with ether. Removal of the ether gave a gum (2·66 g.). This was filtered in benzene solution through silica gel (60 g.) to furnish a clear viscous oil (2·47 g.). The latter (2·40 g.) in "AnalaR" acetone (150 ml.) was stirred for 24 hr. at room temperature with powdered potassium permanganate (8·0 g.; added portionwise). Treatment with sulphur dioxide, addition of water, and extraction with ether gave a non-crystalline acid (1·76 g.). This was suspended in aqueous 0·87N-potassium hydroxide (20 ml.), and powdered potassium permanganate (2·1 g.) added with stirring during 2 hr. at room temperature. Additional potassium permanganate (200 mg.) was not consumed during a further 2 hours' stirring. After passage of sulphur dioxide and addition of dilute sulphuric acid, extraction with chloroform furnished an acid (1·0 g.). Extraction with light petroleum (b. p. 40—60°) gave a soluble acidic oil (665 mg.) and an insoluble residue. The light petroleum solution of the former was chromatographed over silica gel. Elution with benzene gave 1-methyl*cyclo*hexane-1-carboxylic acid (XIV) (312 mg.), identified by m. p., mixed m. p., and conversion into the *p*-bromophenacyl ester (m. p. and mixed m. p.) and *S*-benzylthiuronium salt (m. p. and mixed m. p.).

The authentic specimen of 1-methyl*cyclo*hexyl-1-carboxylic acid was prepared [13] by carboxylation of the Grignard derivative of 1-methyl*cyclo*hexyl chloride.[14] It was converted into the p-*bromophenacyl ester*, m. p. 57·5—58·5° [from light petroleum (b. p. 40—60°)] (Found: C, 56·45; H, 5·7; Br, 22·7. $C_{16}H_{19}O_3Br$ requires C, 56·65; H, 5·65; Br, 23·55%), and the S-*benzylthiuronium salt* (from aqueous ethanol), m. p. 135—136° (139—140° after drying for 60 hr. at room temperature over phosphoric oxide *in vacuo*) (Found: C, 63·25; H, 7·85; N, 9·2. $C_{16}H_{24}O_2N_2S$ requires C, 62·3; H, 7·85; N, 9·1%); for characterisation (see above).

Oxidation of Methylphloracetophenone.—Anhydrous sodium carbonate (12·5 g.) in water (165 ml.) was deaerated with nitrogen (oxygen-free); methylphloracetophenone [15] (5·0 g.) was added and brought into solution by gentle warming. The solution was cooled to 0° and potassium ferricyanide (6·75 g., 1 mol.) in water (160 ml.) was added slowly under nitrogen (oxygen-free) during 30 min. with good stirring. After a further 30 minutes' stirring, the clear, red solution was acidified with 6N-sulphuric acid and extracted with ether. Removal of the ether after drying (Na_2SO_4) furnished a residue which was repeatedly digested with cold chloroform. The residue (2·1 g.), mainly starting material, was discarded. Removal of the chloroform gave a brown foam (2·8 g.). This was chromatographed in benzene over silica gel (75 g.). Elution with ether–benzene (2 : 98) (1800 ml.) gave traces of material which were not investigated further. Elution with ether–benzene (5 : 95) (1200 ml.) afforded the dimer, 2 : 6-*diacetyl*-3 : 4 : 4*a* : 9*b*-*tetrahydro*-1 : 4*a* : 7 : 9-*tetrahydroxy*-8 : 9*b*-*dimethyl*-3-*oxobenzofuran* (XVII) (395 mg. pure), prisms (from benzene), m. p. 192° (decomp.), $\lambda_{max.}$ 228, 284, and 329 mμ (ε 20,000, 24,800, and 3700 respectively), $\lambda_{min.}$ 252 and 327 mμ (ε 11,800 and 3600 respectively) (Found: C, 59·75; H, 5·0. $C_{18}H_{18}O_8$ requires C, 59·65; H, 5·0%). Elution with ether–benzene (1 : 9; 1 l.) gave back starting material (m. p., mixed m.p., and ultraviolet absorption spectrum) (100 mg.). Elution with ether–benzene (1 : 4; 1600 ml.) furnished only traces of material. Elution with ether–benzene (1 : 1; 2400 ml.) gave a compound, prisms (from dioxan or from acetone–ethyl acetate), m. p. 291—292° (decomp.), the nature of which was not investigated further.

The best yield of the dimer (XVII) was obtained as follows. Methylphloracetophenone (2·36 g.) in water (150 ml.) containing anhydrous sodium carbonate (6·0 g.) was oxidised with potassium ferricyanide (6·5 g., 1·5 mol.) essentially as described above. Chromatography over silica gel (50 g.) and elution with ether–benzene (5 : 95; see above) gave pure dimer (XVII) (367 mg., 15%). No starting material was recovered.

(±)-*Usnic Acid.*—The dimer (XVII) (200 mg.) in acetic anhydride (2 ml.) containing concentrated sulphuric acid (0·5 ml. per 100 ml. of acetic anhydride) was heated at 40° (water-bath) for 30 min. After cooling to 0°, the solution was poured on ice (20 g.). Filtration gave crude (±)-usnic acid diacetate (115 mg.). Three recrystallisations from benzene–methanol afforded pure (±)-usnic acid diacetate (60 mg.), m. p. and mixed m. p. 205—207°. The identity

[13] Cf. Gutt, *Ber.*, 1907, **40**, 2069; Schuerch and Huntress, *J. Amer. Chem. Soc.*, 1949, **71**, 2233.
[14] Brown and Borkowski, *ibid.*, 1952, **74**, 1894.
[15] Curd and Robertson, *J.*, 1933, 437.

was confirmed by identical ultraviolet ($\lambda_{max.}$ 223 mμ, inflections at 243 and 307 mμ; ε 25,400, 17,700, and 8200 respectively) and infrared spectra ($CHCl_3$ solution) and by hydrolysis to (±)-usnic acid as follows. The synthetic diacetate (10 mg.) was added to ice-cold concentrated sulphuric acid, left for 5 min., and poured on ice. Extraction with chloroform and crystallisation from methanol gave pure (±)-usnic acid, identified by m. p. and mixed m. p. (195°) and ultraviolet absorption spectrum ($\lambda_{max.}$ 234 and 282 mμ; ε 32,900 and 24,300: $\lambda_{min.}$ 255 mμ; ε 12,700), identical with that of an authentic specimen.

A one-step conversion of the dimer (XVII) into (±)-usnic acid was secured as follows. The dimer (XVII) (364 mg.) was treated in three portions with concentrated sulphuric acid (3 ml. for each portion) at 0° for 5 min., the initial gummy mass being stirred with a rod until dissolved. The solutions were poured on ice and extracted with chloroform. Removal of the chloroform from the combined extracts and crystallisation ten times from ethanol gave pure (±)-usnic acid (8 mg.), identified by m. p., mixed m. p., and ultraviolet absorption spectrum (see above).

(±)-*Usnic Acid "iso Methoxide."*—The monoacetate (XVIII; R = H, R′ = Ac, R″ = OMe), m. p. 178°, of this compound was prepared according to Takahashi.[19] The monoacetate (96 mg.) was dissolved in concentrated sulphuric acid (1 ml.) at 0° and the solution poured on ice. Crystallisation from methanol gave (±)-*usnic acid "iso methoxide"* (XVIII; R = R′ = H, R″ = OMe) (56 mg.), m. p. 188—190°, $\lambda_{max.}$ 226 and 283 mμ (ε 19,800 and 24,900 respectively), $\lambda_{infl.}$ 330 mμ (ε 3400), $\lambda_{min.}$ 251 mμ (ε 11,700) (Found: C, 60·55; H, 5·6. $C_{19}H_{20}O_8$ requires C, 60·65; H, 5·35%).

The usnic acid used in this work was generously provided by Professor and Mrs. N. A. Sörensen and Dr. T. Bruun (Trondheim). We thank the Government Grants Committee of the Royal Society, the Central Research Fund of London University, and Imperial Chemical Industries Limited for financial assistance. One of us (O. E. E.) is on leave of absence from the National Research Council, Ottawa; another (A. M. D.) is indebted to the Stiftung für Stipendien auf dem Gebiete der Chemie (Switzerland) for a Post-doctorate Fellowship. The initial experiments on the constitution of the dimer (VII) from *p*-cresol were kindly carried out by Dr. R. B. Kelly, now of Merck and Co., Montreal, Canada.

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109. *Polarography in Fused Salts. The Dipping Platinum Microelectrode.*

By S. N. Flengas.

The behaviour of a dipping platinum microelectrode has been investigated in the case of silver nitrate dissolved in molten potassium nitrate–sodium nitrate. The solubility products of silver chloride and bromide, determined in this solvent by amperometric titration, agreed well with those determined by electrometric titration.

The application of the polarographic method of analysis to solutions of fused salts has been attempted only recently. Nachtrieb and Steinberg [1] studied the behaviour of the dropping mercury electrode in solutions of fused salts and obtained typical polarographic waves with several metallic cations dissolved in suitable low-melting solvents. However, the use of this electrode is obviously limited at higher temperatures by the volatility of mercury. An attempt, by the same authors, to use dropping electrodes of pure molten lead, bismuth, and silver was unsuccessful.

The use of a dipping platinum microelectrode in the analysis of fused salts was first described by Lyalikov and Karmazin.[2] Using molten potassium nitrate as a suitable solvent at 360°, they obtained well-defined polarograms for silver, cadmium, and lead cations and for the chromate anion. The decomposition potential of the solvent

[1] Steinberg and Nachtrieb, *J. Amer. Chem. Soc.*, 1948, **70**, 2613; 1950, **72**, 3558.
[2] Lyalikov and Karmazin, *Zavod. Lab.*, 1948, **14**, 144; *Zhur. Analit. Khim.*, 1953, **8**, 38.

electrolyte, under these conditions, was about −1·1 v against a platinum needle reference electrode. The use of silicate melts as solvents was also investigated but without success.

Since but few analytical methods are available for investigating fused salt systems, it was decided to make a further study of the behaviour of the dipping platinum electrode under controlled experimental conditions, and the method was applied to the determination of the solubility products of some sparingly soluble silver salts dissolved in a potassium nitrate–sodium nitrate eutectic melt.

Experimental

The current–voltage curves were recorded automatically on photographic paper by use of a Cambridge polarograph which was operated under a rate of potential change of 5·08 mv/sec. The microelectrode was similar to that of Lyalikov and Karmazin,[3] and is shown in Fig. 1. It consisted of a platinum needle, 1 mm. in diameter and 3 mm. long, sealed at the end of a soda-glass tube and surrounded by another glass tube open at the end. Dry, oxygen-free nitrogen was allowed to pass through this outer tube and escaped as bubbles, the electrode thus being periodically dipped and isolated from the surrounding solution. A constant rate of

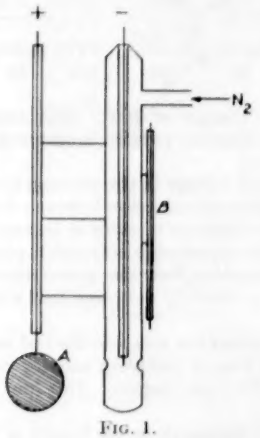

Fig. 1.

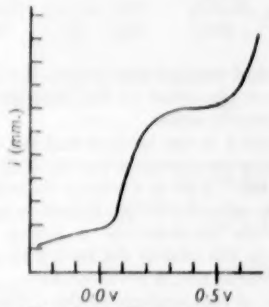

Fig. 2. *Polarographic wave of silver in the nitrate melt solvent at* 250° c.

nitrogen gas flow was achieved with the aid of a Mariotte flask, where, by adjusting the effective water level, it was possible to obtain bubbling rates of between 0 and 250 bubbles per min. (b. p. m.), the number being counted audibly.

A platinum disc (*A*) 2 cm. in diameter was used as a reference non-polarised electrode. The depth of immersion of the cathode, on which the hydrostatic back-pressure of the liquid in the outer tube depends, was maintained the same in all experiments, being adjusted with the aid of an auxilliary depth indicator electrode (*B*). The electrode system was rigidly clamped in position, and vertical movement was adjusted by means of a micrometer screw.

At the beginning of a run, the cathode terminal of the polarograph was connected to the indicator electrode, the anode terminal being always connected to the reference electrode. Then the electrode system was slowly lowered into the melt in the cell until a deflection of the spot of light in the galvanometer scale of the polarograph indicated that electrical contact had been established. The cathode terminal of the polarograph was then connected back to the dipping electrode, and the run started. The cell consisted of a 100-ml. Pyrex beaker in a tubular electric furnace, the temperature of which was controlled up to 350° with an accuracy of ±0·5° by means of a bimetallic strip and thermovalve regulator. Temperatures were determined with a 3″ partial immersion thermometer calibrated by suitable freezing-point measurements up to 327° (m. p. of lead).

At the end of a run the electrodes were cleaned by reversing the polarities and passing a current in the opposite direction for a few minutes.

To prepare the melts "AnalaR" salts were used. A stock of an equimolar mixture of

potassium nitrate and sodium nitrate was prepared by melting the two salts together and mixing them, and pouring the homogeneous melt into glass tubes where it was allowed to solidify quickly, thus avoiding the formation of density gradients by gradual cooling. These were then kept in a desiccator before use. Concentrated solutions of the metallic salts in this solvent were then prepared and used to prepare the more dilute ones.

Results.—The behaviour of the dipping platinum microelectrode with silver nitrate dissolved in the nitrate melt was first studied. The wave of the silver ion appears at about −0·05 v against the platinum reference electrode (Fig. 2), and is as well defined as the polarographic waves obtained with the usual dropping electrode in aqueous solutions. The shape of the wave depends on the temperature of the melt: the nearer to the solidification point of the melt, the better the shape of the wave.

The residual current of the solvent melt is also dependent on temperature. On increase of temperature from 250° to 350°, the residual current increases and at the higher temperature the wave of silver ion is almost undetectable. Furthermore the decomposition potentials are also affected by temperature. In Table 1 the decomposition potentials of silver nitrate and of

TABLE 1. *Results for* $C_{AgNO_3} = 6{\cdot}7 \times 10^{-4}$ *mole*/1000 *g.*

	$-E_{dec.}$ (mv)			$-E_{dec.}$ (mv)			$-E_{dec.}$ (mv)			$-E_{dec.}$ (mv)		
t (°c)	$AgNO_3$	$KNO_3 + NaNO_3$	*t* (°c)	$AgNO_3$	$KNO_3 + NaNO_3$	*t* (°c)	$AgNO_3$	$KNO_3 + NaNO_3$	*t* (°c)	$AgNO_3$	$KNO_3 + NaNO_3$
242	50	670	260	45	620	294	40	520	322	30	440

the background solvent are shown for a temperature change of 100°. The decomposition potentials were measured on the photographic paper by drawing parallel tangents to the rising portions of the two waves.

From Table 1, it can be seen that the operable range of voltage in the polarograms decreases with increasing temperature, and at 350° only ions capable of reduction between 0·0 and 0·4 v can be detected. This is a serious drawback to the use of molten nitrates as solvent.

The small value for dE/dt for silver indicates that no appreciable activation polarisation is involved in the reduction at a bright platinum electrode: but the pronounced effect of temperature in the case of the background salt ($KNO_3 + NaNO_3$) indicates that a rather large activation polarisation is involved here.

The effect of temperature on the diffusion current of silver ion was also studied and is shown in Fig. 3(*a*), where results were obtained at a constant rate of bubbling and for constant salt concentration. The average value for di/dt is about 0·70% per degree. This low value again indicates a process controlled purely by diffusion.

For a constant rate of gas bubbling and at constant temperature the height of the polarographic wave was found to be strictly proportional to the salt concentration over a wide range of concentrations. This is illustrated in Fig. 3(*b*). On the other hand, for constant silver-ion concentration and constant temperature the diffusion current was found to depend on the bubbling rate (n). This is shown in Fig. 4, where the relation is tested for different temperatures and found to be linear. From the results in Fig. 4 the product ($i_d\sqrt{\tau}$), where i_d is the diffusion current in mm. and τ is the bubbling time expressed in sec. per bubble ($\tau = 60/n$), is found to be practically constant (Table 2). This relationship, which indicates that the diffusion current is

TABLE 2. $C_{AgNO_3} = 6{\cdot}85 \times 10^{-4}$ *mole*/1000 *g.*

$t = 242°$			$t = 262°$			$t = 316°$		
i_d (mm.)	n (b.p.m.)	$i_d\sqrt{\tau}$	i_d (mm.)	n (b.p.m.)	$i_d\sqrt{\tau}$	i_d (mm.)	n (b.p.m.)	$i_d\sqrt{\tau}$
54	100	43·2	62	100	49·6	77	100	61·6
68	150	42·8	77	150	48·6	95	150	60·0
77	200	42·3	92	200	50·6	112	200	61·6

inversely proportional to the square root of the time of contact of the electrode with the surrounding solution, was predicted and found experimentally by Laitinen and Kolthoff [8] to apply also in the case of linear diffusion towards a plane platinum microelectrode. Thus the diffusion problem in the case of a periodically dipping cylindrical microelectrode approximates to one of

[8] Kolthoff and Lingane, "Polarography," I, Interscience, New York, 1952.

linear diffusion towards a plane microelectrode of the same total area which periodically increases and decreases. Probably during the short time of contact between the electrode and the surrounding solution, the diffusion layer cannot expand to a considerable distance into the solution and therefore the effect of curvature of the electrode surface is negligible.

Unfortunately, the hydrodynamics of the state of flow in the neighbourhood of a dipping microelectrode are not well defined owing to uncertainties concerning the layer of solution

FIG. 3.

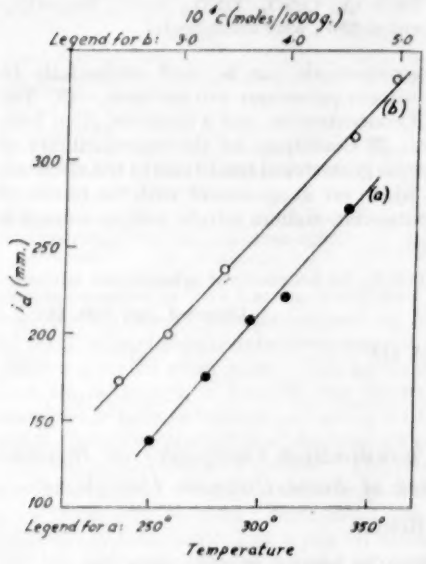

FIG. 5.

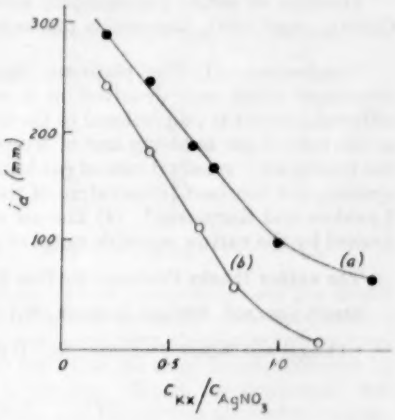

FIG. 3. Polarograph sensitivity = 1/100; n = 100 b.p.m.

(*a*) Temperature effect: $C_{AgNO_3} = 2{\cdot}44 \times 10^{-4}$ mole/1000 g.

(*b*) Calibration straight line: $t = 266°$.

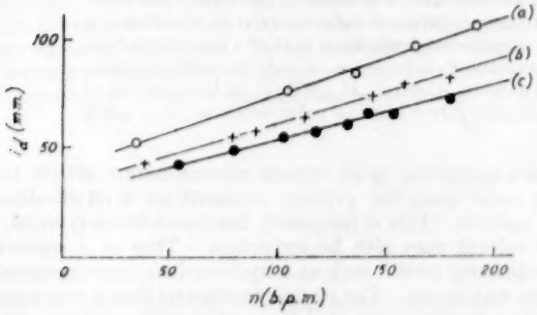

FIG. 4.

Polarograph sensitivity = 1/100; $C_{AgNO_3} = 6{\cdot}85 \times 10^{-4}$ mole/1000 g.
(*a*) $t = 316°$; (*b*) $t = 262°$; (*c*) $t = 242°$.

which is permanently adsorbed by adhesion and surface tension on the electrode surface, even when removed from the melt, etc., and the theoretical equation which can readily be derived on the above assumptions was found to agree only qualitatively with the experimental results. However, the shape of the current–time curve during a complete cycle (time τ), predicted by this equation, was in qualitative agreement with the one obtained experimentally on the screen of a low-frequency oscillograph.

The solubility products of some sparingly soluble salts of silver, *i.e.*, the chloride and bromide, in this melt were next measured by amperometric titration. A solution of silver nitrate in the melt was prepared, and the decrease of the silver wave was followed on the addition of increasing amounts of potassium chloride and bromide, severally. The results of these titrations are shown in Fig. 5, from which the solubility products can be calculated as follows.

We have $K_{s(AgX)} = [Ag^+][X^-]$, where $[Ag^+]$ is measured experimentally from the height of the polarographic wave and is the concentration of unbound halide ions. This is calculated from the total silver nitrate concentration and the total amount of added reagent by use of :

$$[X^-] = C_{KX} - (C_{AgNO_3} - [Ag^+])$$

The following average values are thus obtained for the solubility products at 250° : chloride, $(3{\cdot}95 \pm 0{\cdot}35) \times 10^{-4}$; bromide, $(7{\cdot}15 \pm 0{\cdot}75) \times 10^{-6}$. These are in good agreement with those obtained by electrometric titration,[4] *viz.*, $4{\cdot}89 \times 10^{-4}$ and $7{\cdot}61 \times 10^{-6}$, respectively.

Attempts to obtain polarographic waves for $Pb(NO_3)_2$, $CuSO_4$, $TlNO_3$, $ZnSO_4$, $Hg(NO_3)_2$, $Cd(NO_3)_2$, and $NiSO_4$, dissolved in this molten solvent at 250°, were unsuccessful.

Conclusions.—(1) The platinum dipping microelectrode can be used successfully to determine silver ions dissolved in a sodium nitrate–potassium nitrate melt. (2) The diffusion current is proportional to the silver salt concentration, and a linear function both of the rate of gas bubbling and of temperature. (3) Conditions for the reproducibility of the results are : constant rate of gas bubbling, same geometrical conditions of the electrode system, and constant temperature of the melt, which are in agreement with the results of Lyalikov and Karmazin.[2] (4) The use of the potassium–sodium nitrate melt as solvent is limited by the narrow operable range of potential.

The author thanks Professor Sir Eric Rideal, F.R.S., for his constant interest and advice.

KING'S COLLEGE, STRAND, LONDON, W.C.2. [*Received, July 27th*, 1955.]

[4] Flengas and Rideal, *Proc. Roy. Soc.*, 1956, **233**, *A*, 443.

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110. *Ionisation Equilibria of Metal Co-ordination Complexes in Benzene Solution. Part II.* The Structures of Some Cuprous Complexes.*

By A. R. BURKIN.

Measurements of electrical conductivity in benzene solution show that certain complexes of cuprous halides exist in solution in more than one form. Di-(*o*-phenylenebisdimethylarsine)copper(I) di-iodocuprite(I) in nitrobenzene behaves as a salt, but in benzene the conductance is that of a non-electrolyte. The corresponding bromo-compound behaves as a salt in both solvents. The compound, of empirical formula $[CuBr(C_{18}H_{22}{\cdot}NH_2)_2]$, in benzene has at first the conductance of a non-electrolyte but the value increases as a salt is slowly formed.

A SOLUTION of a pure metal complex compound in an organic solvent cannot always be regarded as a simple system. In some cases the product obtained on crystallisation depends on the composition of the solvent. This is frequently due to solubility relations, but the physical properties of the solvent may also be important. Thus in a solvent of low dielectric constant and co-ordinating power, such as a hydrocarbon, rearrangement of a salt to form a non-ionic complex may occur. The reverse transformation, a non-ionic compound producing a salt in solution, would be expected to occur in such a solvent only under exceptionally favourable conditions (see Part I). The change must have a low activation energy so that in the absence of a catalyst only those metals giving labile complexes would be expected to show such a change. Also, the non-ionic compound would have to be prepared under conditions less favourable for salt formation than those under which dissociation does occur.

Complexes of cuprous halides are labile and are very sensitive to changes of solvent and other experimental conditions. The fact that a compound of empirical formula $CuXA_2$ (A being a monodentate ligand) could exist either as a salt $[CuA_4][CuX_2]$ or as a bridged dimer $[A_2CuX_2CuA_2]$ permits investigation of the possibility that such a compound might

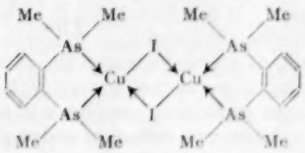
* Part I, *J.*, 1954, 71.

have different structures in different solvents. These points are well shown by the compounds formed between cuprous salts and *o*-phenylenebisdimethylarsine [1] and methyldiphenylarsine.[2] The solvents used for preparing these complexes were of relatively high dielectric constant and both salts and non-ionic compounds were obtained. The molecular constitutions of the substances isolated were investigated in solution by measuring molecular weights under various conditions, and electrical conductivities in nitrobenzene solution. In this paper the electrical conductivities in benzene solution of several such compounds and of some amine complexes are reported. Representative results are shown in the Table; some

Compound	Concn. $\times 10^4$ (M)	Temp.	$10^6\Lambda_M$	$10^{12}\sigma/\sqrt{c}$ at $c = 0$
$[Cu(AsMePh_2)_4]ClO_4$	5·15	35°	5·15	58
$[Cu(diarsine)_2]Br$	10·09	35	8·34	55
$[Cu(diarsine)_2][CuBr_2]$	8·33	33	10·61	63
$[CuI(AsMePh_2)_2]$	20·35	37	0·993	4·7
$CuI(diarsine)]_2$	12·48	35	1·23	6·5
$[CuI(C_{14}H_{27}\cdot NH_2)]$	41·1	30	1·54	4·6
$[CuBr,2C_{12}H_{25}\cdot NH_2]_2$	10·1	35	5·48	38
	26·6	15	3·83	10
	44	20	1·35	3·8
$[Cu(AsMePh_2)_4]NO_3$	2·73	13	3·19	21
$[Cu(AsMePh_2)_4]NO_3$ (from acetone–light petroleum)	0·935	28	0·190	1·3

values reported in Part I are included for comparison. In all cases except one the results confirm the type of formula assigned by Nyholm (non-ionic or ionic). The conductance of tetrakis(methyldiphenylarsine)copper(I) nitrate was lower than that expected by comparison with the other salts. This agrees with the low value obtained in nitrobenzene by Nyholm, although in benzene the discrepancy is smaller. When the compound was dissolved in light petroleum containing a little acetone, and the solvent allowed to evaporate, a crystalline product was obtained with conductance characteristic of a non-electrolyte. This was not investigated further. The conductance of the original nitrate did not change irreversibly when the solution was kept at 45° for several hours.

Kabesh and Nyholm [1] formulated the compound di-(*o*-phenylenebisdimethylarsine)-copper(I) di-iodicuprite(I) as a salt on account of its conductivity in nitrobenzene, which was too large for a non-electrolyte although smaller than those of the other compounds studied. As they point out, the results indicate only that in the solvent used the solute exists as a salt, but they do not establish with certainty that the compound is not bridged under other conditions. In benzene the conductance of the compound is that of a non-electrolyte and does not change irreversibly when the solution is warmed or stored. This suggests that in this solvent the compound exists as the halogen-bridged dimer as shown :



On the other hand the analogous dibromocuprite(I), $[Cu(diarsine)_2][CuBr_2]$ has a conductance in benzene characteristic of a salt and shows no tendency to form non-electrolytes. Thus the supposition that complexes of this type might exist as salts in nitrobenzene and solvents of high dielectric constant and as non-electrolytes in hydrocarbons, is untrue, although this does occur in the one case described.

The analogous compounds of methyldiphenylarsine formulated by Nyholm [2] as $[Cu(AsMePh_2)_4][CuX_2]$, where X = Cl or Br, gave low conductivities in nitrobenzene solution, and from these and molecular-weight determinations he concludes that this information does not permit a certain decision as to the structure of this class of compound. He considers it probable, however, that in the solid state they are salts but that in solution

[1] Kabesh and Nyholm, *J.*, 1951, 38.
[2] Nyholm, *J.*, 1952, 1257.

they undergo extensive dissociation, forming non-electrolytes, the most likely reaction being

$$4[Cu(AsMePh_2)_4][CuX_2] \longrightarrow 4[CuX,(AsMePh_2)_3] + [CuX,AsMePh_2]$$

The compound[3] of empirical formula $CuBr(C_{12}H_{25}\cdot NH_2)_2$ has a molecular weight in freezing benzene corresponding very closely to that required by the dimeric bridged structure (1028). In boiling hexane and boiling benzene the experimental figures are respectively 650 and 445. In cold benzene, and hence presumably in the solid state, the compound appears, therefore, to exist as a bridged dimer but in the hot solvents dissociation occurs. This was postulated to lead to the formulation of $[CuBr(C_{12}H_{25}\cdot NH_2)]_4$ and free amine. Formation of $[CuBr(C_{12}H_{25}\cdot NH_2)_3]$ is improbable since no compound of that composition has been prepared. The observed molecular weights in hot solvents would also be explained by dissociation of a bridged complex to form a salt, as mentioned above. These values would then indicate that the salt was completely dissociated for the purpose of boiling-point elevation. This is frequently true for complex salts in a variety of solvents.

To distinguish between the two modes of dissociation the conductance of the compound in benzene solution was measured. The criterion that the complex should be prepared under conditions less favourable for salt formation than those under which dissociation is studied was fulfilled since the complex was prepared in the *n*-hexane fraction, b. p. 68—72°, of light petroleum, free from unsaturated and aromatic hydrocarbons. The measurements were complicated since the complex is rapidly oxidised when dissolved in, or wet with, a solvent. Even traces of oxygen in commercial hydrogen and nitrogen, purified by passing through alkaline pyrogallol or over hot copper, caused decomposition. The most satisfactory atmosphere was hydrogen passed through platinised asbestos at 350° and dried finally by phosphoric oxide. This, however, caused slow reduction of the complex in solution, increasing the conductivity very considerably. A number of results at different concentrations obtained by standardising conditions of dissolution, using both gases, gave a smooth curve on plotting log c against log $\sigma/\sqrt{c}$, parallel with those obtained for other compounds (see Part I) and it is considered that these results are reliable.

The results given in the Experimental section (*b*) show that with an atmosphere of hydrogen the compound had the conductance of a non-electrolyte when prepared and dissolved with rigorous precautions against oxidation and heating above 20° at any stage after the initial preparation of the compound. At 20° the conductance rose slowly, and at 40° rapidly. Oxidation caused it to fall again.

In section (*c*) it is shown that, in an atmosphere of hydrogen or nitrogen, samples which had been prepared or dissolved at higher temperatures gave solutions of higher molar conductance, the values being easily reproducible and much too high for a non-electrolyte, although low for a salt. It is believed that in such solutions partial dissociation to a salt has occurred and the conductance continues to rise slowly.

Results in section (*d*) show that under hydrogen the rate of rise increases with time until after some days the conductance reaches a very high value. (Similar figures are found after keeping many halogen-containing complexes of copper or bivalent palladium and platinum with amines, phosphines, and arsines in sealed glass bulbs in benzene solution under hydrogen at about 40° for some time. In many cases traces of metal are produced after a few days, and the high conductance is obviously associated with reduction.) Under nitrogen the rise proceeds similarly for a few hours and then the rate of increase gets slower and eventually the conductance may begin to fall again. The deceleration of the change and later fall are accompanied by indications that oxidation is occurring. In view of the small quantities of complex present and the relatively large volume of gas contained in the apparatus, a very small oxygen content would permit oxidation of a large proportion of the compound.

These results suggest that the rise in conductance is associated with the formation of a compound which is more readily reduced by hydrogen and oxidised by gaseous oxygen than that originally present in the solution. This increased reactivity made it impossible to measure the conductance of the pure product.

[3] Wilkins and Burkin, *J.*, 1950, 127.

It is concluded that the complex $[CuBr(C_{12}H_{25}\cdot NH_2)_2]$ exists in benzene solution as a halogen-bridged dimer but that it changes irreversibly to a compound giving many more ions in the solution, probably $[Cu(C_{12}H_{25}\cdot NH_2)_4][CuBr_2]$. No new evidence can be obtained in this way concerning whether or not dissociation to the tetrameric monoamine compound and free amine occurs in hot solutions before salt formation. Evidence as to the changes occurring in the system based on chemical reaction and isolation of solids is obviously unreliable because of the disturbing factors introduced. The compound $[CuBr,C_{12}H_{25}\cdot NH_2]_4$ is very difficult to obtain and work with in a reasonably pure state, but a few results indicate that in the presence of a little free amine the conductance is small. The analogous iodide is easier to handle but its conductance varies greatly with the amount of free amine added to aid solution, being small with about 0·3 mol. of amine present and increasing considerably with smaller amounts, decomposition and precipitation being evident after some time.

It is apparent that in the case of the complexes of an element such as univalent copper it is not possible to be certain of the species present in a solution of a pure compound. Change of solvent can cause a change in the structure of the substance, and even in hydrocarbons dissociation can occur. In the latter case the most frequent changes are from salt to non-electrolyte, but the reverse change is possible also.

Experimental

(*a*) Electrical conductivity was measured by the method described in Part I. The molar conductance Λ_M varies greatly with changing concentration and for comparison between different compounds the value $\sigma/\sqrt{c}$ at zero concentration (σ is specific conductance at concentration c) is used.

(*b*) $CuBr(C_{12}H_{25}\cdot NH_2)_2$ was prepared by the method described previously [3] except that the suspension was filtered through a sintered-glass disc, the funnel being connected to the flask in which the compound was prepared by means of a ground-glass joint. An atmosphere of hydrogen, which had been passed over platinised asbestos at 350°, through a trap at −80°, and over phosphoric oxide, was used and the solid was completely dried in the gas stream before being exposed to air. When prepared by dissolving the cuprous bromide in the solution of dodecylamine in light petroleum at 40° and cooling the solution rapidly to 20° as soom as all traces of solid had disappeared, the compound was white and when dry acquired a green tint in air only after several hours.

A $4{\cdot}4 \times 10^{-3}$M-solution of the white solid (based on M, 1028 for the dimeric structure), prepared by dissolving it at 20° in benzene, gave a practically colourless solution with Λ_M 1·35 $\times 10^{-6}$ at 20°. After 16 hr. at 20° Λ_M was $2{\cdot}88 \times 10^{-6}$ but after storage at 40° for 20 min. and cooling to 20°, it rose to $4{\cdot}64 \times 10^{-6}$. The solution was now pale green. A little dry air was mixed with the hydrogen stream bubbling through the solution and within a few minutes the conductance began to fall. After an hour the solution was pale brown; it darkened slowly, and Λ_M reached $1{\cdot}27 \times 10^{-6}$ at 15° and $1{\cdot}69 \times 10^{-6}$ at 42° after about 4 hr.

(*c*) Most attempts to prepare the complex resulted in products with a pronounced green tint, giving pale green benzene solutions. Five such solutions with c between 15×10^{-4} and 4×10^{-3}M gave values of Λ_M of between about 3×10^{-6} and 6×10^{-6}. The log $\sigma/\sqrt{c}$ against log c curve was parallel with that for *cis*-$Pt(Et_2P)_2Cl_2$ (see Part I) and gave a value of $\sigma/\sqrt{c}$ at $c = 0$ of $10{\cdot}0 \times 10^{-12}$ at 20°.

(*d*) A dilute solution with $c = 10^{-3}$ was stirred with hydrogen under about 2 atm. pressure at 35°. The conductance increased slowly as shown. Zero time was about 30 min. after dissolution.

Time (hr.)	0	0·17	0·33	1·25	1·75	2·25	3·0	17·5	22
$10^6\Lambda_M$	5·5	5·8	6·3	7·6	7·9	8·6	12·2	90·5	123

The author thanks Professor R. S. Nyholm for supplying the complexes of methyldiphenylarsine and *o*-phenylenebisdimethylarsine and for helpful discussion.

Royal School of Mines, London, S.W.7. [*Received, August 16th,* 1955.]

111. *Cationic Polymerisation of Oxacyclobutanes. Part I.*

By J. B. Rose.

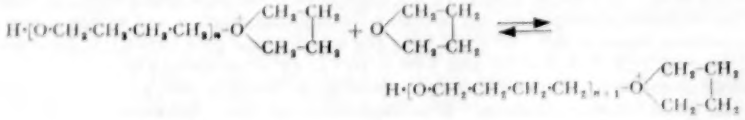
The cationic polymerisation of oxa*cyclo*butane to a mixture of a linear polyether and a cyclic tetramer is described. The effects of temperature on this reaction are reported and discussed. 3 : 3-Dimethyloxa*cyclo*butane polymerised to a mixture of polymer and tetramer, but 2-methyloxa*cyclo*butane gave only linear polymer. The polymers of oxa*cyclo*butane and its 3 : 3-dimethyl analogue are crystalline, but poly-2-methyloxa*cyclo*butane is amorphous.

SEVERAL examples of the cationic polymerisation of cyclic ethers (I) to linear polyethers having the repeating unit $\cdot[CH_2]_n\cdot O\cdot$ have been reported. Staudinger and Lehmann [1] have investigated the stannic chloride-catalysed polymerisation of ethylene oxide, and the cationic polymerisation of tetrahydrofuran, discovered by Meerwein,[2] has been described by other German workers.[3] Delfs [3] states that oxa*cyclo*butane reacts in the same way, but does not give details, and Farthing and Reynolds [4] have described the polymerisation of 3 : 3-bischloromethyloxa*cyclo*butane, which is catalysed by boron trifluoride. Only linear polymers of oxa*cyclo*butanes have been reported. The present work was undertaken to investigate the polymerisation of several oxa*cyclo*butanes, for which no detailed information was available.

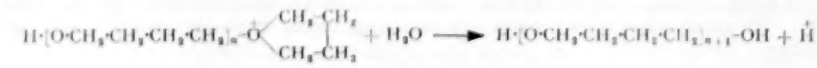
Oxa*cyclo*butane polymerised on addition of catalytic quantities of boron trifluoride, the experimental method being such that adventitious water was excluded as far as possible from the system. The product was a mixture of a crystalline polyether of high molecular weight (m. p. *ca.* 35°), and a tetramer, $(C_3H_6O)_4$, which melted sharply at 70°. The infra-red absorption spectrum of the tetramer contained a strong band at 1120—1130 cm.$^{-1}$ characteristic of a strainless ether linkage, but no bands characteristic of hydroxyl, carbonyl, or >C=C< groups were present. There was no absorption band at 1378 cm.$^{-1}$ where a terminal methyl group would be expected to absorb. 1 : 3-Dichloropropane was the only compound isolated (in 50% yield) from the reaction of the tetramer with hydrochloric acid at 100°. These data are consistent with the tetramer's having the structure (II).

(I) $\overline{\text{[}[CH_2]_n\cdot O\text{]}}$ $\qquad\qquad$ $\overline{\text{[}[CH_2]_3\cdot O\cdot[CH_2]_3\cdot O\cdot[CH_2]_3\cdot O\cdot[CH_2]_3\cdot O\text{]}}$ (II)

Delfs [3] considered that the polymerisation of tetrahydrofuran proceeded *via* a tertiary oxonium ion, and formulated polymerisation and depolymerisation as follows:



On treatment with water the oxonium ion decomposed to give a hydroxyl-terminated polymer molecule:



Oxa*cyclo*butane being assumed to react by a similar mechanism, a 16-membered ring could be formed by reaction of the oxonium ion with the appropriate ether linkage in the polymer chain. No homologues of the tetramer could be isolated, indicating that, in this polymerisation, a 16-membered ring is formed more readily than any other ring.

[1] Staudinger and Lehmann, *Annalen*, 1933, **505**, 41.
[2] Meerwein, G.P. 741,478.
[3] Delfs, Microfilm F.D. 156/48, Leverkusen 13th Oct., 1941; Hamann, *Angew. Chem.*, 1951, **63**, 231.
[4] Farthing and Reynolds, *J. Polymer Sci.*, 1954, **12**, 503; Farthing, *J.*, 1955, 3648.

The effect of temperature on the polymerisation of oxa*cyclo*butane is illustrated in Table 1. An increase in temperature increases the proportion in which the reaction yields tetramer, but decreases both the molecular weight of the polymer, and the ultimate conversion of monomer into polymer and tetramer. Delfs [3] states that an equilibrium between monomer and polymer is established during the polymerisation of tetrahydrofuran, and it has been shown [5] that the equilibrium concentration of monomer increases with temperature. However, it is apparent from the last experiment in Table 1 that, in

TABLE 1. *Polymerisation of oxacyclobutane catalysed by boron trifluoride.*

($[BF_3]$ = 0·010 mole l.$^{-1}$)

Temp	Reaction time (days)	Conversion (%)	Proportion of tetramer (%)	$[\eta]$ (dl. g.$^{-1}$)	Temp.	Reaction time (days)	Conversion (%)	Proportion of tetramer (%)	$[\eta]$ (dl. g.$^{-1}$)
−80°	14	85	4	2·9	50°	28	62	62	1·1
−80	28	95	4	2·6	50 *	14	78	65	0·8
−80 *	14	92	5	2·1	100	7	29	63	1·6
0	14	94	10	2·1	100	14	37	68	—
0 *	14	98	9	1·7	100	28	31	60	—
50	7	62	58	1·1	21 days at −80°, then				
50	14	64	66	1·3	28 days at 100°		89	6	1·6

* In these experiments the monomer was diluted with its own volume of ethyl chloride. In the other experiments the monomer was not diluted.

the case of oxa*cyclo*butane, the decrease in percentage conversion brought about by an increase in temperature is not an equilibrium phenomenon. This effect may be due to the destruction of the catalyst at the higher temperature by side reactions. Theoretically it is unlikely that the polymerisation would be reversible under these conditions, for it has been estimated [6] that the free energy change of the (hypothetical) polymerisation of a liquid *cyclo*alkane at 25° to polymethylene is −21·5 kcal. mole^{-1} for *cyclo*butane, but only −2·2 kcal. mole^{-1} for *cyclo*pentane. Small [7] has indicated that substitution of one methylene group in the *cyclo*alkane by an oxygen atom would affect these figures only slightly, and on this basis there would be *ca.* 2% of tetrahydrofuran in equilibrium with its polymer (at 25°) but the equilibrium concentration of oxa*cyclo*butane would be very small.

Boron trifluoride dihydrate also catalysed the polymerisation of oxa*cyclo*butane, but the rates were slow and the polymers were of low molecular weight. When mixtures of water with boron trifluoride were used, erratic results were obtained and in several cases explosions resulted. The effect of added water has been investigated in greater detail and is reported in Part II.[8]

3 : 3-Dimethyloxa*cyclo*butane polymerised in the presence of boron trifluoride dihydrate to give a mixture of a crystalline polymer of low molecular weight (m. p. *ca.* 45°) and a tetramer of m. p. 157° whose infrared absorption spectrum was similar to that of the tetramer prepared from oxa*cyclo*butane, and indicated the absence of all functional groups other than the ether group. Attempts to split the molecule with hydrochloric acid at 100° were unsuccessful, the tetramer being recovered unchanged. However, if the structure of this tetramer is analogous to structure (II) then the steric hindrance afforded by the methyl groups attached to the β-carbon atoms would increase the resistance of the ether linkages to hydrolysis.

2-Methyloxa*cyclo*butane polymerised in the presence of boron trifluoride ($[BF_3]$ = 0·10 mole l.$^{-1}$), but the polymer, which was of high molecular weight ($[\eta]$ = 2·9 dl. g.$^{-1}$), was amorphous. Oxa*cyclo*butane and its 3 : 3-dimethyl derivative are symmetrical molecules and can therefore give polymers of regular structure. Poly-2-methyloxa*cyclo*butane, however, should have an irregular structure, for the monomer contains an asymmetric carbon atom, and monomer can add to the growing chain to form a di-primary ($\cdot CH_2 \cdot O \cdot CH_2 \cdot$),

[5] L. S. Rayner, personal communication.
[6] Dainton, Devlin, and Small, *Trans. Faraday Soc.*, in the press.
[7] Small, *ibid.*, in the press.
[8] Rose, following paper.

a primary-secondary (·CH_2·O·CHMe·), or a di-secondary (·CHMe·O·CHMe·) ether linkage. Thus the state, either crystalline or amorphous, of these polymers can be correlated with their structures, for it is generally accepted that a polymer must possess a considerable degree of structural regularity if it is to crystallise. Oxa*cyclo*butane and its 2-methyl derivative form copolymers which, as expected, are amorphous.

Experimental

Microanalyses and molecular-weight determinations were carried out in the Analytical Department of this Division.

Preparation of Monomers.—(a) *Oxacyclobutane.* 1-Acetoxy-3-chloropropane was prepared by a modification of Bogert and Slocum's method.[9] These authors claimed that high yields were obtained when equimolar quantities of acetyl chloride and propane-1 : 3-diol reacted in a Carius tube, and were then heated to 100° for 8 hr. However, repetition of this procedure, followed by fractionation of the product, showed that a mixture of all the possible substitution products was obtained, the principal components of which were 3-chloropropanol and 1-acetoxy-3-chloropropane. An indication of what occurs in the sealed tube, after the initial reaction, was obtained from measurements of the concentrations of chloride and acetate ions that were extracted from the product by shaking it with water (Table 2).

Table 2. *Reaction of acetyl chloride with propane-1 : 3-diol.*

Time of heating at 100° (hr.)	0	2	4	8
Material lost as OAc^- (%)	16·5	26·9	30·8	34·4
Material lost as Cl^- (%)	51	14·5	9·9	5·3

The following preparative procedure was therefore adopted. The diol (4 mole), contained in a large Carius tube (about 700 ml. capacity), was cooled to −80°, and precooled acetyl chloride (4 mole) added. The tube was sealed and placed in an ice-bath, whereupon a vigorous reaction occurred. After being kept overnight, the tube was heated at 100° for 8 hr. Acids were then removed by treatment with potassium carbonate solution, and the product was distilled to give a colourless liquid, b. p. 50—100°/14 mm. This was acetylated at 100° with acetyl chloride (2 mole), and after acidic impurities had been removed the product was fractionated at reduced pressure to give a 65% yield of 1-acetoxy-3-chloropropane, b. p. 66·5—66·8°/14 mm. (Found : Cl, 25·9. Calc. for $C_5H_9O_2Cl$: Cl, 26·0%). Bennett and Heathcoat [10] record b. p. 66°/14 mm.

Oxa*cyclo*butane was prepared by the action of alkali on 1-acetoxy-3-chloropropane, according to Searles's procedure.[11] It was purified by refluxing it with, and distilling it from, freshly fused potassium hydroxide and fractionating the distillate, all these operations being carried out under nitrogen. The fraction, b. p. 48°/770 mm., n_D^{20} 1·3929 (Barrow and Searles [12] report b. p. 47°/750 mm., n_D^{25} 1·3893), was collected, dried *in vacuo* (BaO), and distilled in a good vacuum into the storage section of the polymerisation apparatus (Found : C, 62·1; H, 10·7. Calc. for C_3H_6O : C, 62·0; H, 10·4%).

(b) 2-*Methyloxa*cyclo*butane.* A mixture of acetoxychlorobutanes, CH_3·CHCl·CH_2·CH_2·OAc and CH_3·CH(OAc)·CH_2·CH_2Cl, b. p. 73·3—76·9°/15 mm. (Found : C, 48·0; H, 7·6; Cl, 24·3. Calc. for $C_6H_{11}O_2Cl$: C, 47·9; H, 7·4; Cl, 23·6%), was prepared from butane-1 : 3-diol in 70% yield, by the method described above for 1-acetoxy-3-chloropropane. 2-Methyloxa*cyclo*butane was prepared from the mixture of chlorobutyl acetates in 42% yield by the action of alkali, according to Searles's procedure for oxa*cyclo*butane.[11] This monomer, purified as described above, had b. p. 59·7—59·8°/760 mm., n_D^{20} 1·3919 (Found : C, 66·6; H, 11·3. Calc. for C_4H_8O : C, 66·6; H, 11·2%). Barrow and Searles [12] record b. p. 60°/747 mm., n_D^{20} 1·3890.

(c) 3 : 3-*Dimethyloxa*cyclo*butane.* 1-*Acetoxy*-3-*chloro*-2 : 2-*dimethylpropane*, b. p. 67·9—68·2°/10 mm., n_D^{20} 1·4325 (Found : C, 51·8; H, 8·3; Cl, 21·3. $C_7H_{13}O_2Cl$ requires C, 51·1; H, 8·0; Cl, 21·4%), was prepared in 83% yield from the corresponding diol by a slight modification of the method described above for 1-acetoxy-3-chloropropane. The initial reaction between 2 : 2-dimethylpropane-1 : 3-diol (prepared according to Whitmore *et al.*[13]) and acetyl chloride was carried out at 20°, and the Carius tubes were then heated to 140° for 48 hr. The acetylation and isolation procedures were as described above.

[9] Bogert and Slocum, *J. Amer. Chem. Soc.*, 1924, **46**, 763.
[10] Bennett and Heathcoat, *J.*, 1929, 271.
[11] Searles, *J. Amer. Chem. Soc.*, 1951, **73**, 124.
[12] Barrow and Searles, *ibid.*, 1953, **75**, 1175.
[13] Bernstein, Popkin, Whitmore, and Wilkins, *ibid.*, 1941, **63**, 126.

Application of Searles's procedure, for the preparation of oxa*cyclo*butane, to the action of alkali on 1-acetoxy-3-chloro-2 : 2-dimethylpropane gave very low yields of the cyclic ether, the principal product being *iso*butene (identified by its infrared absorption spectrum). Searles and Garlatowski [14] have reported that *iso*butene is the main product from the reaction of 3-bromo-2 : 2-dimethylpropanol with alkali. The following procedure was therefore adopted. Pentyl alcohol (400 ml.) was heated under reflux to 80°, and potassium hydroxide flakes (4 mole) added with constant stirring. When the alkali had dissolved, 1-acetoxy-3-chloro-2 : 2-dimethylpropane (1 mole) was added during 2 hr., the internal temperature being maintained between 100° and 110°. The liquid was distilled (stirring was continued to expedite the distillation), and the fraction of b. p. 70—135° collected. After being dried (K_2CO_3), this was fractionated to give two fractions : (1) b. p. 69—80° and (2) b. p. 80—83°; much pentyl alcohol remained in the pot. Fraction (1) was dried (K_2CO_3), refluxed with sodium, distilled, and added to fraction (2). The liquid so obtained was refluxed over sodium wire for several hours, then fractionated from the sodium (these operations being carried out under nitrogen) to give pure 3 : 3-dimethyloxa*cyclo*butane, b. p. 81·0°/765 mm., n_D^{20} 1·3980 (Found : C, 69·8; H, 11·9. Calc. for $C_5H_{10}O$: C, 69·7; H, 11·7%) in 40% yield. Barrow and Searles [13] record b. p. 76—78° for this compound, and Bennett and Philip [15] b. p. 78°/742 mm.

Solvents.—Ethyl chloride and methyl chloride, obtained from cylinders, were passed through sulphuric acid and stored *in vacuo* over calcium hydride.

Catalysts.—Boron trifluoride was prepared as described previously,[16] and the dihydrate according to Shirley.[17]

Polymerisation Techniques.—(a) *Polymerisations catalysed by boron trifluoride.* Measured quantities of monomer, solvent (when required), and catalyst were distilled *in vacuo* into a constricted glass tube cooled in liquid nitrogen. The tube was sealed, and warmed to the required temperature. Polymers of oxa*cyclo*butane were isolated by dissolving the contents of the tube in ether and, after ammonia had been passed in, cooling the solution to −80°, whereupon the polymer crystallised out and was filtered off. The frozen polymer was freed from solvent by placing it in a vacuum-desiccator, which was then evacuated continuously for 24 hr. Evaporation of the mother-liquor gave a crystalline material from which a tetramer was isolated (see below). Polymers of 2-methyloxa*cyclo*butane, and copolymers of this monomer with oxa*cyclo*butane, were isolated by dissolving the polymerisation product in ethanol and precipitating the polymer with distilled water. Volatile impurities were pumped off, leaving extremely viscous oils, which did not crystallise at room temperature or at −80°.

(b) *Polymerisations catalysed by boron trifluoride dihydrate.* Oxa*cyclo*butane (195 g.) and methyl chloride (490 ml.) were distilled, *in vacuo*, into a flask, fitted with a mechanical stirrer and a reflux condenser, which was cooled by liquid nitrogen. The mixture was warmed to −60°, and boron trifluoride dihydrate (22·1 ml.) added. Polymerisation commenced and the solvent refluxed vigorously. After 18 hr. the product was poured into ether (2 l.) and, when the methyl chloride had boiled off, the solution was treated, first, with aqueous sodium hydroxide, and then with water. After drying (K_2CO_3), polymer and tetramer were isolated as described above. The yield of polymer, m. p. 25°, $[\eta]$ *ca.* 0·05 dl. g.$^{-1}$, was 171 g., and the yield of tetramer 1 g.

The polymerisation of 3 : 3-dimethyloxa*cyclo*butane (175 g.) in ethyl chloride (490 ml.) solution, catalysed by boron trifluoride dihydrate (22·1 ml.), was carried out according to the procedure described in the previous paragraph. Evaporation of the ether solution gave a crystalline mass which was stirred and heated to 130° at 0·05 mm. for 24 hr., during which crystalline material distilled and condensed on the upper parts of the vessel. Thus were obtained 123 g. of polymer, m. p. 45°, $[\eta]$ *ca.* 0·05 dl. g.$^{-1}$, and 40 g. of crystalline material from which a tetramer was isolated (see below).

Viscosity Measurements.—The intrinsic viscosities of the polymers in benzene solution were measured at 20° with an Ostwald No. 1 viscometer.

Tetramers.—(a) 1 : 5 : 9 : 13-*Tetraoxa*cyclo*hexadecane.* Purification of the crude *tetramer* (obtained as described above) by sublimation at 0·6 mm. followed by recrystallisation from absolute ethanol at −80° gave white crystals, m. p. 70° [Found : C, 61·1; H, 10·6%; *M* (Rast), 230; *M* (Menzies–Wright), 223. $C_{12}H_{24}O_4$ requires C, 62·0; H, 10·4%; *M*, 232].

Tetramer (8 g.) and fuming hydrochloric acid (120 ml.) were heated in a sealed tube to 100°

[14] Searles and Garlatowski, *J. Amer. Chem. Soc.*, 1953, **75**, 3030.
[15] Bennett and Philip, *J.*, 1928, 1937.
[16] Barr and Rose, *J.*, 1953, 3766.
[17] Shirley, "Preparation of Organic Intermediates," John Wiley and Sons, Inc., New York, 1951, p. 35.

for 7 days with constant shaking. The organic material was extracted with pentane, dried (K_2CO_3), and fractionated to give 1 : 3-dichloropropane (8 g., 51%), b. p. 119°/748 mm., n_D^{20} 1·4484 (Found : Cl, 62·2. Calc. for $C_3H_6Cl_2$: Cl, 62·7%) : Smyth and McAlpine [18] record b. p. 120·2°/750 mm., n_D^{20} 1·4488.

(b) **3 : 3 : 7 : 7 : 11 : 11 : 15 : 15-*Octamethyl*-1 : 5 : 9 : 13-*tetraoxa*cyclo*hexadecane*.** The material (90 g.) obtained from polymerisations of 3 : 3-dimethyloxa*cyclo*butane was sublimed at 130° in a good vacuum. Recrystallisation of the sublimed material from absolute ethanol gave the *tetramer* (33 g.), m. p. 157° [Found : C, 69·4; H, 11·5%; *M* (Menzies–Wright), 331. $C_{20}H_{40}O_4$ requires C, 69·7; H, 11·7%; *M*, 344]. Evaporation of the mother-liquors gave a sticky material (36 g.) which, after recrystallisation from acetone at −80°, had m. p. 44°. The infrared absorption spectrum of this material was identical with that of hydroxyl-terminated poly-3 : 3-dimethyloxa*cyclo*butane of low molecular weight.

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Welwyn Garden City, Herts. [*Received, September 2nd*, 1955.]

[18] Smyth and McAlpine, *J. Amer. Chem. Soc.*, 1935, **57**, 979.

112. *Cationic Polymerisation of Oxacyclobutanes. Part II.**

By J. B. Rose.

A kinetic investigation of the polymerisation of oxa*cyclo*butane, catalysed by boron trifluoride, is described. Water, ethanol, and hydroxyl-terminated polymer are cocatalysts for the reaction. The rate of polymerisation obeys the equation, rate $= k[M][BF_3][R{\cdot}OH]$ (R = H, Et, polymer chain) provided that, with 0·1M-boron trifluoride as the catalyst, the concentration of cocatalyst is not greater than 0·01M. When the concentration of water was increased from 0·01M to 0·03M the rate passed through a maximum, after which further increase in the concentration of water brought about a marked decrease in rate. Increase in the concentration of water above 0·01M also changed the order of reaction with respect to monomer progressively from 1 to 2. The molecular weight of the polymer (as indicated by its intrinsic viscosity) decreased steadily as the concentration of cocatalyst was increased. From the above data, polymerisation mechanisms are proposed involving chain propagation *via* oxonium ions. The method of kinetic measurement also enabled the heat of polymerisation, which provides a measure of the ring-strain energy of the oxa*cyclo*butane ring, to be determined. Investigation of the polymerisation of 3 : 3-dimethyloxa*cyclo*butane indicated that it followed a course analogous to that of the parent compound.

In the presence of boron trifluoride both oxa*cyclo*butane and its 3 : 3-dimethyl analogue are polymerised to a mixture of a cyclic tetramer and a linear polymer.* The present investigation was undertaken to determine the factors affecting both the rate of polymerisation and the molecular weights of the polymers produced. The temperature was chosen so that linear polymer was the principal product. All chemicals were handled *in vacuo*, and the kinetic measurements were made by measuring the rate at which the heat of reaction was evolved under isothermal conditions.

Experimental

Materials.—Oxa*cyclo*butane, 3 : 3-dimethyloxa*cyclo*butane, ethyl chloride, methyl chloride, and boron trifluoride were obtained, purified, and stored as in Part I. Ethanol, used as a cocatalyst, was dried by Smith's method.[1] Poly(oxa*cyclo*butane) of low molecular weight had $[\eta]$ *ca.* 0·05 dl. g.$^{-1}$, and was prepared as in Part I.

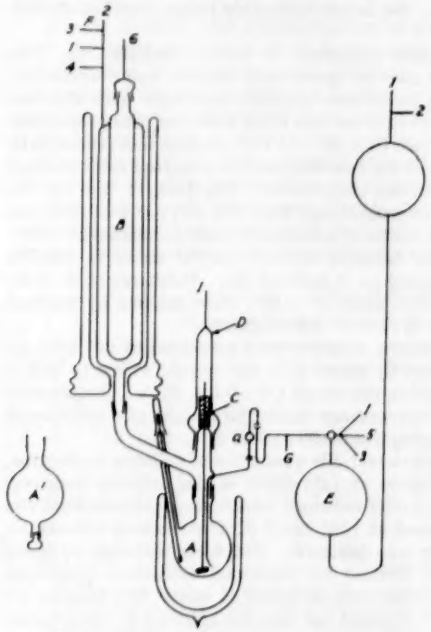
Apparatus.—This is shown in Fig. 1, and was designed so that the reaction vessel, *A* (*ca.* 300

* Part I, preceding paper.

[1] Smith, *J.*, 1927, 1288.

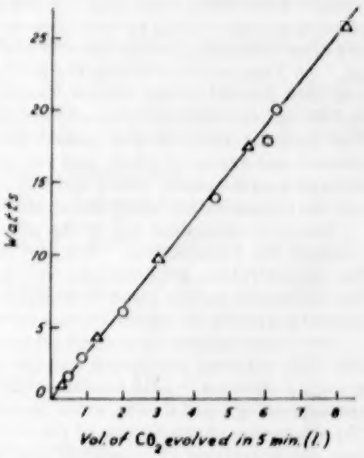
ml. capacity), could be charged with reactants *in vacuo*, then filled with dry nitrogen and the polymerisation carried out at atmospheric pressure. The condenser, *B*, and the reaction vessel, *A*, were insulated thermally by vacuum jackets, while the tubes connecting them, and the mouth of the vacuum flask surrounding *A*, were lagged with cotton-wool. A pentane thermometer projected into *A*, but was attached to a sealed glass tube containing soft iron so that it could be withdrawn by means of a magnet. The stirrer gland, *C*, which was made of "Neoprene" and lubricated with Silicone grease, effectively prevented ingress of moisture during polymerisation when a slight positive pressure of nitrogen was maintained in *A*, but was surrounded by the adaptor, *D*, when a vacuum was required in the apparatus. The gas pipette,

FIG. 1.



1, To pump.
2, To atmosphere.
3, To nitrogen supply.
4, To monomer and solvent supplies.
5, To BF_3 supply.
6, To flow meter.

FIG. 2.



○, Methyl chloride.
△, Methyl chloride–ethyl chloride.

E (1·2 l. capacity), was filled with dry mercury. All ducts opening to the atmosphere were protected by long guard tubes packed with calcium hydride to prevent the entry of moisture. The nitrogen used was dried by being passed through a similar tube.

Procedure.—(1) The apparatus was evacuated overnight by means of a two-stage oil-pump pumping through a trap cooled in liquid nitrogen. (2) Measured quantities of monomer, cocatalyst (water or ethanol), and solvent were distilled, in this order, into the reaction vessel which was cooled in liquid nitrogen, the thermometer being withdrawn. When polymer of low molecular weight was used as the cocatalyst, it was placed in the reaction vessel when the apparatus was assembled, and heated to 130° while the apparatus was evacuated. Measurements of the intensity of the infrared absorption band at *ca.* 5100 cm.$^{-1}$, due to water, showed that the above treatment reduced the water content of the polymer to a negligible level. After the polymer had been dried, the other reactants were distilled into the reaction vessel without discharging the vacuum. (3) The condenser was filled with a mixture of solid carbon dioxide (700 g.) and ethanol (100 ml.), and dry nitrogen passed into the apparatus until the pressure inside it was 1 atm. Thereafter a flow of nitrogen was maintained across the junction, *F*.

The adaptor, *D*, could now be removed, allowing the stirrer to be connected to an electric motor. Then the reaction vessel was warmed until its contents, which were vigorously stirred, refluxed against the condenser, and the apparatus was insulated thermally as described in the previous paragraph. (4) A measured quantity of boron trifluoride was distilled from a constant-volume variable-pressure gas-burette into the tube, *G*, which was cooled in liquid nitrogen. It was then warmed so that it vaporised and displaced mercury from bulb, *E*, the upper bulb being evacuated. When the boron trifluoride had vaporised completely, the lower bulb was opened to the atmosphere so that the gas in the lower bulb was under pressure. (5) The reaction vessel having reached thermal equilibrium with its surroundings, polymerisation was initiated by injecting boron trifluoride from the bulb, *E*, into the reaction vessel *via* the tap, *a*, and immediately afterwards flushing the dead space between *A* and *E* with a slow stream of dry nitrogen. The complete operation took *ca.* 3 min., the boron trifluoride being absorbed during this period.

Polymers.—Three methods were used to isolate polymers of oxa*cyclo*butane. (*a*) The reactant product was poured into ether and, when most of the methyl chloride had evaporated, the ether extract was washed, first with sodium hydroxide solution and then with distilled water. After being dried (K_2CO_3), the polymer was isolated free from tetramer (the proportion of tetramer was $<10\%$) by crystallisation at $-80°$ (see Part I). (*b*) The product was poured into dry ether containing trichloroacetic acid (0·6 g.), and the resulting solution treated as in method (*a*). (*c*) This was used to stop the polymerisation before completion. The flask, *A'* (see Fig. 1), was used instead of the reaction vessel and at a predetermined time the stopper was removed and the reaction solution blown by nitrogen into a solution of sodium ethoxide in ethanol at $-20°$. The resulting mixture was poured into ether, the solution washed several times to remove ethanol and excess of alkali, and the polymer isolated as in method (*a*). Polymers of 3 : 3-dimethyloxa*cyclo*butane, which did not crystallise from ether at $-80°$, were isolated by method (*a*), the ether solution being evaporated to dryness to recover the polymer.

Intrinsic viscosities, $[\eta]$, of the polymers in benzene solution were measured at 20° with an Ostwald No. 1 viscometer. The plot of η_{sp}/C against C, where η_{sp} is the specific viscosity and C the concentration, gave straight lines in the concentration range 1·0—0·2 g. dl.$^{-1}$. Osmometric measurements gave a value of 20,000 for the number-average molecular weight of a mixture of several polymers of oxa*cyclo*butane having $[\eta]$ ranging from 0·60 to 0·54 dl. g.$^{-1}$.

Polymers isolated by method (*a*) did not contain detectable quantities of chlorine or fluorine, but their infrared absorption spectra contained bands characteristic of the primary hydroxyl group at 3300 cm.$^{-1}$ (OH fundamental), 4700 cm.$^{-1}$ (OH overtone which was resolved from the corresponding band due to water at 5100 cm.$^{-1}$), and at 1045 cm.$^{-1}$ (C–O stretching vibration). No absorption characteristic of the $>C{:}CH_2$ group was detected. Polymers prepared by using low concentrations of cocatalyst and isolated by method (*b*) contained detectable quantities of chlorine (see Tables 5 and 7), but an increase in the concentration of water to 0·10 mole l.$^{-1}$ (the concentration of catalyst being 0·10 mole l.$^{-1}$) reduced the chlorine content of the polymer to 0·1%. Polymers isolated by method (*a*) from blank experiments, in which solutions of hydroxyl-terminated polymer in ether were treated with trichloroacetic acid both in the absence and in the presence of boron trifluoride, did not contain detectable quantities of chlorine. The intrinsic viscosities of polymers isolated by method (*c*) from repetitions of experiment 1 (see Table 1) in which the reaction was stopped after approximately 50%, 75%, and 100% of the monomer had reacted were 1·10, 0·90, 0·56 dl. g.$^{-1}$, respectively. The intrinsic viscosity of hydroxyl-terminated polymer was unchanged when a solution of the polymer in methyl chloride was treated with boron trifluoride.

Kinetic Method.—Polymerisations were followed by measuring the rate at which heat was evolved, and transferred by the refluxing solvent to the condenser. This was effected by measurement of the volume of carbon dioxide evolved from the freezing mixture in the condenser, at intervals during the reaction, by means of a gas-meter which could be read to 0·01 l. The total volume of carbon dioxide evolved provided a direct measure of the heat of reaction, while the rate of evolution measured the reaction rate. Blanks were run immediately before and after the polymerisation, and the mean value obtained (*ca.* 0·3 l. min.$^{-1}$) used to correct for heat entering the system owing to imperfect insulation. The method was calibrated by replacing the pentane thermometer (see Fig. 1) by a small electric heater, and comparing the rate of carbon dioxide evolution with the wattage of the heater. Heat evolution in the reaction vessel was registered almost immediately on the flow-meter, and the volume of carbon dioxide evolved was proportional to the energy dissipated by the heater (see Fig. 2). The refluxing solvent was methyl chloride, or ethyl chloride–methyl chloride (1 : 1).

Rate measurements made at the start of the reaction were disturbed because the catalyst, which dissolved relatively slowly, was not added instantaneously. Therefore an arbitrary zero of time was taken after the catalyst had been added, and first- and second-order integrated rate constants were calculated according to the equations $k_1 = 2{\cdot}303\{\log_{10} a/(a - x)\}/t$ and $k_2 = x/(a - x)ta$, respectively, where $a = V_\infty - V_0$ and $x = V_t - V_0$, V_∞ being the total volume of carbon dioxide evolved, V_0 that evolved up to the zero of time, and V_t that evolved by time t (measured from the arbitrary zero of time). For the tabulated results the starting monomer concentration was calculated from the volumes of monomer and solvent used, while the "initial" monomer concentration is equal to the "starting" concentration $\times V_0/V_\infty$. Values quoted in the Tables are the average values of k_1 or k_2 for each experiment, a series of constants being calculated for values of x up to 70—80% of a. The deviation from the mean value was *ca.* ±5%.

Kinetic Results.—(a) *Polymerisation of oxacyclobutane in methyl chloride solution at* −22°. Both the order and the rate of the reaction were markedly affected by the concentration of water present in the system (see Table 1). Continual increase in the concentration of added water caused the rate to rise to a maximum and then to decrease, while the apparent order of reaction changed progressively from 1 to 2. The intrinsic viscosities of the polymers decreased as the concentration of added water was increased.

The region ([H_2O] added ranging from zero to 0·0066 mole $l.^{-1}$) in which the reaction obeyed a first-order rate law was investigated in greater detail, as now to be described.

Variation of both the concentration of monomer at the start of the reaction and the "initial" monomer concentration (Table 2) had only a slight effect on k_1, but the intrinsic viscosity of the polymers increased with increasing monomer concentration. This increase in k_1 is largely

TABLE 1. *Effect of added water on the polymerisation.*

(Starting [monomer] = 1·62 mole $l.^{-1}$; [BF_3] = 0·10 mole $l.^{-1}$.)

Expt.	[H_2O] added (mole $l.^{-1}$)	Reaction order	Rate * (mole $min.^{-1}$)	k_1 ($min.^{-1}$)	k_2 ($min.^{-1}$ mole^{-1} l.)	[η] (dl. $g.^{-1}$)
1	Nil	1	0·051	0·083	—	0·60
1 (*a*)	Nil	1	0·053	0·085	—	0·54
2	0·0066	1	0·132	0·212	—	0·47
3	0·010	>1 <2	*ca.* 0·20	—	—	0·54
4	0·030	>1 <2	0·36	—	—	0·52
5	0·050	>1 <2	0·20	—	—	0·50
6	0·070	>1 <2	0·15	—	—	0·46
7	0·080	2	0·13	—	0·325	0·42
8	0·090	2	0·04	—	0·106	0·38
9	0·120	2	0·02	—	0·054	0·34
10	0·150	—	Rate too slow to be measured	—	—	0·16

* The rate quoted is that when the monomer concentration was 0·62 mole $l.^{-1}$, and in expts. 1, 2, 7, 8, and 9 was calculated from the corresponding rate constants. In expts. 3, 4, 5, and 6 the rate was obtained from experimental plots of monomer concentration against time by drawing tangents.

accounted for by the automatic increase in the concentration of water which accompanies an increase in monomer concentration, owing to the relatively inadequate method (as compared with that used for the solvent) of drying the monomer. The reaction is therefore of first order with respect to monomer.

TABLE 2. *Effect of monomer concentration on* k_1.

([BF_3] = 0·10 mole $l.^{-1}$; no water added.)

Expt.	Starting [monomer] (mole $l.^{-1}$)	Initial [monomer] (mole $l.^{-1}$)	k_1 ($min.^{-1}$)	[η] (dl. $g.^{-1}$)	Expt.	Starting [monomer] (mole $l.^{-1}$)	Initial [monomer] (mole $l.^{-1}$)	k_1 ($min.^{-1}$)	η (dl. $g.^{-1}$)
11	0·81	0·30	0·067	0·39	1*a*	1·62	1·12	0·085	0·54
1	1·62	0·90	0·083	0·60	12	2·44	1·08	0·088	0·69

Variation in the concentration of boron trifluoride caused only random fluctuations in the value of $k_1/[BF_3]$ (Table 3), indicating that the reaction was of first order with respect to boron trifluoride.

Addition of small quantities of water or of ethanol to the reaction (Tables 4 and 5) caused the rate constant, k_1, to increase according to the equations, $k_1 = C_{H_2O}\{[H_2O] + 0{\cdot}0045\}$ and $k_1 = 0{\cdot}084 + C_{EtOH}[EtOH]$. Water and ethanol are therefore cocatalysts and, if it is assumed that the concentration of water remaining in the reactants after drying was 0·0045 mole $l.^{-1}$,

the reaction is of first order with respect to the cocatalyst. The value of 0·0045 mole l.$^{-1}$ corresponds to slightly less than one part of water (by vol.) per 10,000 parts of reaction mixture. Addition of water causes only a slight decrease in [η] but addition of ethanol brings about a considerable decrease.

TABLE 3. *Effect of boron trifluoride concentration on k_1.*

(Starting [monomer] = 1·62 mole l.$^{-1}$; no water added.)

Expt.	Initial [monomer] (mole l.$^{-1}$)	[BF_3] (mole l.$^{-1}$)	k_1 (min.$^{-1}$)	k_1/[BF_3] (min. mole^{-1} l.)	[η] (dl. g.$^{-1}$)
13	1·08	0·05	0·035	0·70	0·72
1	0·90	0·10	0·083	0·83	0·60
1*a*	1·12	0·10	0·085	0·85	0·54
14	1·15	0·13	0·094	0·72	—
15	0·86	0·16	0·113	0·71	0·49
16	0·78	0·18	0·131	0·73	0·51
17	0·57	0·20	0·170	0·85	0·44

TABLE 4. *Effect of added water on k_1.*

(Starting [monomer] = 1·62 mole l.$^{-1}$; [BF_3] = 0·10 mole l.$^{-1}$.)

Expt.	Initial [monomer] (mole l.$^{-1}$)	[H_2O] added (mole l.$^{-1}$)	k_1 (min.$^{-1}$)	k/([H_2O] + 0·0045) (min.$^{-1}$ mole^{-1} l.)	[η] (dl. g.$^{-1}$)
1	0·90	Nil	0·083	18·4	0·60
1*a*	1·12	Nil	0·085	18·9	0·54
18	0·85	0·0022	0·136	20·3	0·52
19	0·77	0·0037	0·154	18·8	0·50
20	0·65	0·0058	0·194	18·8	—
2	0·62	0·0066	0·212	19·1	0·47

Average value for C_{H_2O} = 91·1 g. min.$^{-1}$ mole^{-1} l.

TABLE 5. *Effect of ethanol on k_1.*

(Starting [monomer] = 1·62 mole l.$^{-1}$; [BF_3] = 0·10 mole l.$^{-1}$.)

Expt.	Initial [monomer] (mole l.$^{-1}$)	[EtOH] (mole l.$^{-1}$)	k_1 (min.$^{-1}$)	(k_1 − 0·084)/[EtOH] (min.$^{-1}$ mole^{-1} l.)	[η] (dl. g.$^{-1}$)	[Cl] † (%)
1	0·90	Nil	0·083	—	0·60°	—
1*a*	1·12	Nil	0·085	—	0·54	0·2
21	1·06	0·0021	0·115	14·8	0·42	0·2
22	1·07	0·0036	0·131	13·1	0·40	0·2
23	0·82	0·0067	0·175	13·7	0·35	0·3
24 *	—	0·030	—	—	0·27	—

Average value for C_{EtOH} = 13·9 min.$^{-1}$ mole^{-1} l.

* The order of this reaction was $>1<2$.

† The polymers were isolated by method (*b*), and their chlorine content is listed in this column.

Hydroxyl-terminated polymer was also a cocatalyst (Table 6), but as the molecular weight of the polymer was not known with any degree of certainty, the effectiveness of its cocatalysis could not be measured.

TABLE 6. *Effect of hydroxyl-terminated polymer on k_1.*

(Starting [monomer]: 1·62 mole l.$^{-1}$; [BF_3] = 0·10 mole l.$^{-1}$.)

Expt.	Initial [monomer] (mole l.$^{-1}$)	[Polymer] (g. l.$^{-1}$)	k_1 (min.$^{-1}$)	[η] (dl. g.$^{-1}$)
1	0·90	Nil	0·083	0·60
25	0·82	10·7	0·164	0·38
26	0·98	11·0	0·173	0·35

(b) *Polymerisation of oxacyclobutane and 3 : 3-dimethyloxacyclobutane at −9°, a mixture of methyl chloride and ethyl chloride being used as the solvent.* Poly-(3 : 3-dimethyloxa*cyclo*butane) crystallised when this monomer was polymerised in methyl chloride solution at −22°. However, a homogeneous reaction mixture was obtained when ethyl chloride–methyl chloride (1 : 1, by vol.) was used as the solvent. A brief investigation, restricted to the region in which the reactions obeyed first-order rate laws, indicated that for both monomers the addition of small quantities of water (Tables 7 and 8) brought about a linear increase in rate of polymerisation. Expts. 30 and 31 (Table 8) indicate that the polymerisation of 3 : 3-dimethyloxa*cyclo*butane is of first order with respect to boron trifluoride.

Heats of Polymerisation.—The total volume of carbon dioxide evolved from the condenser during each experiment was corrected for the heat of solution of the catalyst, and the value obtained converted into kcal. by means of the conversion factor obtained from Fig. 2 (100w = 6·31. min.$^{-1}$, *i.e.*, 1 l. = 6/6·3 × 4·185 = 0·228 kcal.). The heat of solution of the catalyst, obtained by measurement of the volume of carbon dioxide evolved when boron trifluoride was dissolved in a solution of polymer, was equivalent to 0·7 l. of carbon dioxide per 0·01 mole of boron trifluoride dissolved. In Table 9 the heat of polymerisation of oxa*cyclo*butane is compared with that of its 3 : 3-dimethyl analogue.

The average value of ΔH for the polymerisation of oxa*cyclo*butane in methyl chloride solution at −22° (Expts. 1—25) was 20·0 kcal. mole^{-1}.

TABLE 7. *Effect of added water on the rate of polymerisation of* oxacyclo*butane.*

(Starting [monomer] = 0·81 mole l.$^{-1}$; [BF_3] = 0·040 mole l.$^{-1}$.)

Expt.	Initial [monomer] (mole l.$^{-1}$)	[H_2O] added (mole l.$^{-1}$)	k_1 (min.$^{-1}$)	$k_1/([H_2O] + 0·0025)$ (min.$^{-1}$ mole l.$^{-1}$)	[η] (dl. g.$^{-1}$)	[Cl] * (%)
27	0·66	Nil	0·076	30·4	0·43	0·5
28	0·60	0·00072	0·117	36·3	—	0·3
29	0·60	0·00122	0·127	34·2	—	0·2
30	0·58	0·00161	0·143	34·8	0·41	0·4

* The polymers were worked up by method (*b*) and their chlorine contents are listed in this column.

TABLE 8. *Effect of boron trifluoride concentration and of added water on the rate of polymerisation of* 3 : 3-*dimethyloxa*cyclo*butane.**

(Starting [monomer] = 0·81 mole l.$^{-1}$.)

Expt.*	Initial [monomer] (mole l.$^{-1}$)	[BF_3] (mole l.$^{-1}$)	[H_2O] added (mole l.$^{-1}$)	k_1 (min.$^{-1}$)	$k_1/([H_2O] + 0·0024)$ (min.$^{-1}$ mole l.$^{-1}$)
31	0·44	0·040	Nil	0·111	—
32	0·61	0·020	Nil	0·053	21·9
33	0·55	0·020	0·00067	0·069	22·3
34	0·29	0·020	0·00111	0·078	22·1

* [η] was *ca.* 2 dl. g.$^{-1}$ in all four experiments, but this value is of little significance as the polymers became partially cross-linked during isolation.

TABLE 9. *Heats of polymerisation at −9°, a mixture of ethyl chlorine and methyl chloride being used as the solvent.*

(Starting [monomer] = 0·81 mole l.$^{-1}$.)

(*a*) Oxa*cyclo*butane				
Expt.	27	28	29	30
[BF_3] (mole l.$^{-1}$)	0·040	0·040	0·040	0·040
Vol. of CO_2 evolved (l.) *	13·5	13·6	13·8	13·8
ΔH (kcal. mole^{-1})	19·0	19·1	19·4	19·4
(*b*) 3 : 3-Dimethyloxa*cyclo*butane				
Expt.	31	32	33	34
[BF_3] (mole l.$^{-1}$)	0·040	0·020	0·020	0·020
Vol. of CO_2 evolved (l.) *	11·3	11·4	11·2	11·6
ΔH (kcal. mole^{-1})	15·8	16·0	15·7	16·3

* This volume of gas was evolved when 200 ml. of a 0·81 mole l.$^{-1}$ solution of monomer was polymerised, correction having been made for the heat of solution of the catalyst.

DISCUSSION

The kinetic measurements show that water has a marked effect on the nature of this reaction, complex variations in both rate and order occurring as the concentration of water is changed. However, provided that the concentration of water does not exceed a limiting value, the kinetics of the reaction are described by equation (1), where [H_2O] and [BF_3] are the concentrations of these reactants added to the system. This was demonstrated

$$-d[M]/dt = \text{const.} \times [M][BF_3]([H_2O] + C) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

for the polymerisation of oxa*cyclo*butane in methyl chloride solution, and for both oxa*cyclo*butane and its 3 : 3-dimethyl analogue, a methyl chloride–ethyl chloride being used as the solvent. These data do not show that water is an essential cocatalyst, for reaction occurs

without addition of water. However, Farthing and Reynolds [2] have shown that boron trifluoride is unable to initiate the polymerisation of 3 : 3-bischloromethyloxa*cyclo*butane in an exhaustively dried system, but polymerisation commences on addition of water. Therefore, for discussion of the experiments described in this paper, it appears reasonable to assume that reaction takes place without addition of water because the system is not completely dry, and in equation (1), C is equal to the concentration of water present owing to incomplete drying. A qualitative indication of the polymers' relative molecular weights was obtained from measurements of their intrinsic viscosities. These measurements show that the molecular weight increases with increasing monomer concentration, but decreases as the concentration of added water is increased. The molecular weight also decreases with increasing conversion of monomer into polymer, implying that this polymerisation does not take place by a mechanism of the type described by Hibbert and Perry [3] for the base-catalysed polymerisation of ethylene oxide, in which step-wise addition of monomer to hydroxyl-terminated polymer occurs, and the molecular weight increases as the polymerisation proceeds:

$$OH\cdot[CH_2\cdot CH_2\cdot O]_n\cdot H + \boxed{CH_2\cdot CH_2\cdot O} \longrightarrow OH\cdot[CH_2\cdot CH_2\cdot O]_{n+1}\cdot H$$

Taking the observed dependence of molecular weight on monomer concentration into account, it may be concluded from equation (1) that polymerisation proceeds by a chain mechanism in which the rate of initiation does not depend on the concentration of monomer. Boron trifluoride is only slightly soluble in methyl chloride, but dissolves readily in a solution of oxa*cyclo*butane in methyl chloride owing, presumably, to the formation of a co-ordination compound whose concentration will be that of the boron trifluoride added. A two-stage initiation mechanism, the rate of which does not depend on monomer concentration, is as follows:

$$\boxed{[CH_2]_3\cdot O,BF_3} + H_2O \longrightarrow \boxed{[CH_2]_3\overset{+}{O}\cdot H}\ BF_3OH^- \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (k_4)$$

$$\boxed{[CH_2]_3\cdot O} + \boxed{[CH_2]_3\overset{+}{O}\cdot H}\ BF_3OH^- \longrightarrow HO\cdot[CH_2]_3\cdot\overset{+}{O}\cdot\boxed{[CH_2]_3}\ BF_3OH^- \quad . \quad . \quad (k_4')$$

The chain is then propagated *via* the tertiary oxonium ion:

$$H\cdot\{O\cdot[CH_2]_3\}_n\cdot\overset{+}{O}\cdot\boxed{[CH_2]_3}\ BF_3OH^- + O\cdot\boxed{[CH_2]_3} \longrightarrow H\cdot\{O\cdot[CH_2]_3\}_{n+1}\cdot\overset{+}{O}\cdot\boxed{[CH_2]_3}\ BF_3OH^- \quad . \quad . \quad . \quad (k_p)$$

In accordance with current theory,[4] the anion, BF_3OH^-, is assumed to be closely associated with its cation, the two forming an ion-pair. The reactions of the oxonium ions with monomer are considered, by analogy with the acid-catalysed substitution reactions of ethylene oxide,[5] to involve nucleophilic attack by monomer at the α-carbon atom of the oxonium ion. The secondary oxonium ion should be kinetically distinguishable from the tertiary one, because hydrogen bonding to the anion, possible in the former but not in the latter, reduces the effective positive charge on the oxygen atom and therefore the reactivity at the α-carbon. This distinction is substantiated by the observation [6] that tertiary oxonium ions are among the strongest alkylating agents known, but secondary oxonium ions are far less electrophilic, *e.g.*,[6] secondary salts, $R_2\overset{+}{O}H\overset{-}{X}$ where X is halogen, are known, but attempts to prepare the salt $R_3\overset{+}{O}\overset{-}{I}$ lead to a mixture of alkyl iodide and dialkyl ether.

Polymers isolated from reaction products that had been treated with sodium hydroxide were found to contain primary hydroxyl groups, but in no case could halogen or $>C{:}CH_2$ groups be detected. However, when the reaction product was treated with trichloroacetic acid the polymers isolated always contained chlorine. These facts suggest that

[2] Farthing and Reynolds, *J. Polymer Sci.*, 1954, **12**, 503.
[3] Hibbert and Perry, *J. Amer. Chem. Soc.*, 1940, **62**, 2599.
[4] Pepper, *Quart. Rev.*, 1954, **8**, 88.
[5] Ingold, "Structure and Mechanism in Organic Chemistry," Bell and Son Ltd., London, 1953, p. 345.
[6] Burwell, *Chem. Rev.*, 1954, **54**, 615.

termination occurs through the formation of a strainless, and therefore relatively unreactive, oxonium ion :

$$H\cdot\{O\cdot[CH_2]_3\}_{n+2}\cdot\overset{+}{O}\cdot[CH_2]_3^{-} \longrightarrow H\cdot\{O\cdot[CH_2]_3\}_n\cdot\overset{+}{O}\cdot[CH_2]_3\cdot\{O\cdot[CH_2]_3\}_2^{-} \quad . \quad . \quad . \quad . \quad (k_t)$$

BF_3OH^- BF_3OH^-

When the reaction product is treated with a nucleophilic reagent, X^-, the oxonium ion is destroyed, producing tetramer and polymer containing X as an end group:

$$H\cdot\{O\cdot[CH_2]_3\}_n\cdot\overset{+}{O}\cdot[CH_2]_3\cdot\{O\cdot[CH_2]_3\}_3^{-} + \bar{X} \longrightarrow H\cdot\{O\cdot[CH_2]_3\}_n\cdot X + [\{O\cdot[CH_2]_3\}_4]$$

$(X^- = OH^-, CCl_3\cdot COO^-)$

Tetramer can be produced without the formation of polymer, so that no direct relation exists between the proportions in which the two are produced :

$$H\cdot\{O\cdot[CH_2]_3\}_3\cdot\overset{+}{O}\cdot[CH_2]_3^{-} \longrightarrow [\{O\cdot[CH_2]_3\}_4] + BF_3OH^-H^+$$

BF_3OH^-

Nucleophilic attack on the tertiary oxonium ion by the cocatalyst must be regarded as a chain transfer reaction, for it generates the acid, $BF_3OH^-H^+$, which would rapidly re-form the secondary oxonium ion by proton transfer to monomer :

$$H\cdot\{O\cdot[CH_2]_3\}_{n-1}\cdot\overset{+}{O}\cdot[CH_2]_3^{-} + R\cdot OH \longrightarrow H\cdot\{O\cdot[CH_2]_3\}_n\cdot OR + BF_3OH^-H^+ \quad . \quad . \quad (k_{tr.})$$

BF_3OH^-

$$BF_3OH^-H^+ + O\cdot[CH_2]_3^{-} \longrightarrow H\cdot\overset{+}{O}\cdot[CH_2]_3^{-}\ BF_3OH^- \ \text{(fast)}$$

The degree of chain transfer, as indicated by the decrease in molecular weight that accompanies an increase in the cocatalyst concentration, is small when the cocatalyst is water, but becomes considerable when ethanol is used. This is to be expected because the nucleophilic power of ethanol is greater than that of water.

Stationary concentrations of both the secondary and the tertiary oxonium ions containing strained rings, being assumed, the mechanism postulated in the previous two paragraphs leads to equations (2) and (3), which accord with the experimental observations :

$$d[M]/dt = (k_t k_p/k_t)\ [M][BF_3][R\cdot OH] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\overline{D.P.} = k_p[M]/(k_t + k_{tr.}[R\cdot OH]) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

However, although the kinetics of the polymerisation are described by the third-order equation (2), individual reactions obey the first-order equation (4), where k_1 depends on the concentrations of water and boron trifluoride present at the start of the reaction:

$$-d[M]/dt = k_1[M] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The effective concentrations of water and boron trifluoride must therefore remain sensibly unchanged during the period in which the kinetic measurements are made. Polymerisations where the concentrations of water, boron trifluoride, and monomer used were 0·10, 0·0045, and 1·62 mole $l.^{-1}$, respectively, gave polymer having a molecular weight of 20,000. The concentration of boron trifluoride used was therefore greatly in excess of the concentration of polymer produced (0·0047 mole $l.^{-1}$), but the concentration of water was slightly less than that of the polymer. Thus it appears that, on the basis of the mechanism postulated above, individual reactions should obey a second-order rate law. However, during polymerisation one hydroxyl group is formed for every water molecule used up, and as both ethanol and hydroxyl-terminated polymer are cocatalysts, the primary hydroxyl group can replace water in the initiating process. Further, hydroxyl groups regenerate themselves when they cocatalyse initiation, so that the concentration of cocatalyst (water

plus hydroxyl groups) remains constant throughout the polymerisation, and the first-order rate dependence is qualitatively explained.

The hydroxyl group is quantitatively a less effective cocatalyst than water, so that the explanation given in the previous paragraph must be examined in greater detail. The first-order integrated constant, k_1, for polymerisations cocatalysed by a mixture of ethanol and water is given by

$$k_1 = 19{\cdot}1[H_2O] + 13{\cdot}9[EtOH] \quad (\text{where } [BF_3] = 0{\cdot}10 \text{ mole l.}^{-1}) \quad . \quad (5)$$

If it is assumed that the cocatalytic reactivity of hydroxyl groups attached to polymer molecules is the same as that of ethanol (this appears reasonable, for the hydroxyl group is primary in both cases, and the difference in reactivity between water and ethanol is small), the rate coefficient k_t at time t will vary according to

$$k_t = 19{\cdot}1x + 13{\cdot}9\{[H_2O] - x\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where $[H_2O]$ is the concentration of water at the start and x the concentration remaining at time t. To a first approximation the concentration of water used, $[H_2O] - x$, is given by equation (7) where p is the concentration of polymer and V_{H_2O} and V_{ROH} are the average rates of polymerisation catalysed by water and hydroxyl respectively :

$$[H_2O] - x = pV_{H_2O}/(V_{H_2O} + V_{ROH}) = \frac{p \times 19{\cdot}1([H_2O]) + x)/2}{19{\cdot}1([H_2O] + x)/2 + 13{\cdot}9([H_2O] - x)/2} \quad (7)$$

For the (most critical) case that $[H_2O] = 0{\cdot}0045$ mole l.$^{-1}$ the value of p at the end of the reaction is 0·0047 mole l.$^{-1}$. Substituting $[H_2O] \simeq p = a$, we obtain a quadratic equation in x and a, the positive solution of which is $x = 0{\cdot}30a$. Therefore at the start of the polymerisation $k_t = 0{\cdot}088$ min.$^{-1}$ and at the finish $k_t = 0{\cdot}072$ min.$^{-1}$. Thus k_t decreases by 18% during the complete reaction or by 9% during the period, from 30% to 80% conversion, in which the rate measurements were made. However, the rate constant, k_1, is an integrated constant, and therefore an average value of the instantaneous rate constants, k_t, in the time interval 0—t, so that in practice variations in k_1 may be expected to be within the experimental error (±5%). It is a necessary consequence of cocatalysis by hydroxyl-terminated polymer that combination of the tertiary oxonium ion with its anion does not occur to any detectable extent, for this would cause the molecular weight to increase with increasing conversion of monomer into polymer, whereas the opposite was shown to occur.

Increase in the total concentration of water present in the system from 0·012 to 0·035 mole l.$^{-1}$ ($[BF_3] = 0{\cdot}10$ mole l.$^{-1}$) causes the rate of polymerisation to pass through a maximum, after which further increase in the water concentration decreases the rate. There is a marked decrease in the molecular weight, and the order of reaction with respect to monomer changes from unity ($[H_2O] \leqslant 0{\cdot}012$ mole l.$^{-1}$) to 2 ($[H_2O] \geqslant 0{\cdot}085$ mole l.$^{-1}$). These facts may be explained if it is assumed that proton transfer from the secondary oxonium ion to water increases in importance as the concentration of water increases. Under these conditions the reaction of the secondary oxonium ion with monomer may control the rate of initiation, and the mechanistic scheme must be modified by replacing the first reaction (rate constant k_1) by two equilibria :

$$\boxed{[CH_2]_3{\cdot}\overset{+}{O}{\cdot}BF_3} + H_2O \rightleftharpoons \boxed{[CH_2]_3{\cdot}\overset{+}{O}{\cdot}H}\ BF_3OH^- \quad . \quad . \quad . \quad . \quad . \quad (K_1)$$

$$\boxed{[CH_2]_3{\cdot}\overset{+}{O}{\cdot}BF_3} + 2H_2O \rightleftharpoons \boxed{[CH_2]_3{\cdot}O} + H_3O^+\ BF_3OH^- \quad . \quad . \quad (K_2)$$

Reaction of the cocatalyst with the tertiary oxonium ion now becomes the most important termination step :

$$H{\cdot}\{O{\cdot}[CH_2]_3\}_{n-1}{\cdot}\boxed{\overset{+}{O}{\cdot}[CH_2]_3}\ BF_3OH^- + H_2O \longrightarrow H{\cdot}\{O{\cdot}[CH_2]_3\}_n{\cdot}OH_2^+\ BF_3OH^- \quad . \quad (k_t')$$

A stationary concentration of tertiary oxonium ions being assumed, these modifications to the kinetic scheme lead to equations (8) and (9) :

$$-\mathrm{d[M]}/\mathrm{d}t = (K_1k_i'k_p/k_t')[\mathrm{BF_3,M}][\mathrm{M}]^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\overline{\mathrm{D.P.}} = k_p[\mathrm{M}]/k_t'[\mathrm{H_2O}] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Boron trifluoride dihydrate is the most stable complex present, so that $K_2 \gg K_1$. Thus $[\mathrm{BF_3,M}] = [\mathrm{BF_3}]_s - [\mathrm{BF_3,2H_2O}]$, and to a first approximation $[\mathrm{BF_3,2H_2O}] = \frac{1}{2}[\mathrm{H_2O}]_s$, where the subscript s denotes stoicheiometric, as opposed to equilibrium, reactant concentrations. Equation (8) now becomes :

$$-\mathrm{d[M]}/\mathrm{d}t = (K_1k_i'k_p/k_t')([\mathrm{BF_3}]_s - \tfrac{1}{2}[\mathrm{H_2O}]_s)[\mathrm{M}]^2$$

This provides a qualitative explanation (it cannot be quantitatively correct, for boron trifluoride dihydrate catalyses the reaction, although the rate was too slow to be measured when $[\mathrm{BF_3,2H_2O}] = 0{\cdot}10$ mole l.$^{-1}$) of the kinetic and molecular-weight data obtained for polymerisations where $[\mathrm{H_2O}]_s \geqslant 0{\cdot}085$ mole l.$^{-1}$ and $[\mathrm{BF_3}]_s = 0{\cdot}10$ mole l.$^{-1}$. The maximum rate occurs during the transition from one mechanism, whose kinetics are described by equation (2), to the mechanism postulated in this paragraph.

Values of 19·3 and 16·1 kcal. mole^{-1} were obtained for the heats of polymerisation of oxa*cyclo*butane and 3 : 3-dimethyloxa*cyclo*butane respectively, the reaction being carried out in MeCl–EtCl solution at −9°. It is of interest that this variation is comparable in both magnitude and direction with the difference between the values, estimated by Dainton, Devlin, and Small,[7] for the (hypothetical) heats of polymerisation of *cyclo*butane and its 1 : 1-dimethyl analogue to liquid polymers at 25°. The polymerisation of oxa*cyclo*butane involves the production of a strainless chain from strained rings containing the same number of bonds, so that the heat of polymerisation provides some measure of the strain energy of the oxa*cyclo*butane ring.

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Welwyn Garden City, Herts. [*Received, September 2nd,* 1955.]

[7] Dainton, Devlin, and Small, *Trans. Faraday Soc.*, in the press.

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113. *Interaction of Lewis Acids with Aromatic Hydrocarbons and Bases. Part XVI.* The Association of Chloranil with Methylbenzenes in* cyclo*Hexane.*

By R. Foster, D. Ll. Hammick, and B. N. Parsons.

The degree of interaction of chloranil with a series of methylbenzenes in *cyclo*hexane solution has been determined colorimetrically by using a competitive method described by Corkill, Foster, and Hammick.[1] The free energies of the interactions, evaluated from the association constants, are found to be linearly related to the ionisation potentials of the respective hydrocarbons, as are the energies of excitation of the complexes.

The present work was undertaken to determine the effect of ring methylation of benzene on the stability of the complexes formed with a Lewis acceptor (acid) in solution. Mulliken [2] regards such complexes as the result of interaction of a Lewis donor (base) and a

* The series of papers entitled " Interaction of Polynitro-compounds with Aromatic Hydrocarbons and Bases " are regarded as previous parts of this series. Part XV, *J.*, 1955, 1202.

[1] Corkill, Foster, and Hammick, *J.*, 1955, 1202.
[2] Mulliken, *J. Amer. Chem. Soc.*, 1950, **72**, 605; 1952, **74**, 811; *J. Phys. Chem.*, 1952, **56**, 801.

Lewis acceptor, whereby a complex is formed which is a hybrid of unbonded structures of weak interactions of the component molecules with a contribution of a structure in which an electron has been transferred from the donor to the acceptor molecule. Thus the ground state of the complex may be represented as ψ_N where :

$$\psi_N = a\psi(A, B) + b\psi(A^- - B^+) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

An excited state ψ_E exists where :

$$\psi_E = a^*\psi(A^- - B^+) - b^*\psi(A, B) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

so that an electronic excitation, characteristic of the complex, exists corresponding to the transition $\psi_N \longrightarrow \psi_E$. This absorption is called the charge-transfer band of the complex, and the height of this band is presumably a measure of the charge-transfer interaction.

It is reasonable to expect a relation between such charge-transfer and the ionisation potentials of the aromatic donor molecules; since the present work was commenced, this expectation has been realised by Briegleb and Czekalla [3] who have studied the interaction of methylbenzenes with *s*-trinitrobenzene. Keefer and Andrews [4] have made a similar study of methylbenzene–iodine interactions. Our choice of chloranil as an acceptor was determined by the wish to extend the scanty systematic knowledge of this Lewis acid in interactions of the type we are studying. Our results will be seen to run parallel to those of the authors mentioned above.

The determinations by both Andrews and Briegleb depend on direct measurements of the enhancement of absorption due to charge transfer when the components are mixed. In the present work, a different method for determining the association constants has been employed. It depends on the measurement of the depression of charge-transfer absorption of a complex by adding a third substance which will compete with one of the components in the complex for the second component of the complex. A full account of the method has already been given.[1,5] It has the advantage that optical measurements can be made at a wavelength at which the components of the complex do not absorb, by choosing a suitable acid or base against which the other base or acid can compete. The method has already been justified by comparison of the association constant of *s*-trinitrobenzene–benzene determined by this competitive method,[1] with the result obtained by direct measurement of the *s*-trinitrobenzene–benzene charge-transfer band.[6]

Two corrections have had to be applied in the determinations. The first is a compensation for instrumental error. Vandenbelt, Forsyth, and Garrett [7] show that, with a Beckman DU spectrophotometer, the plot of extinction coefficient against optical density is only linear from $D = 0{\cdot}45$ to $D = 1{\cdot}9$; indeed, even over this central range a slight variation persists. This non-linearity occurred also with the Unicam SP 600, the instrument used in the present work, and was discovered from check measurements with aqueous potassium chromate solutions. All values of D given are corrected to compensate for this instrumental error. Where possible, optical densities have been kept above 0·45 to minimise such effects. It was also found that the values of K obtained by the competition method were dependent on the concentration of the methylbenzene; the association constants can however be extrapolated to zero concentration of methylbenzene. This extrapolation gives consistent results, which agree with the values obtained from the direct measurement of the charge-transfer absorption of the complex by the method of Foster, Hammick, and Wardley.[8]

Experimental.—Materials. *cyclo*Hexane was purified by passing it through silica gel (30/120 mesh; 50 cm. × 3·5 cm.) which had been heated to 250°, subsequently washed with water and

[3] Briegleb and Czekalla, *Z. Electrochem.*, 1955, **59**, 184.
[4] Keefer and Andrews, *J. Amer. Chem. Soc.*, 1955, **77**, 2164.
[5] Foster, *Nature*, 1954, **173**, 222.
[6] Lawrey and McConnell, *J. Amer. Chem. Soc.*, 1952, **74**, 6174.
[7] Vandenbelt, Forsyth, and Garrett, *Ind. Eng. Chem. Anal.*, 1945, **17**, 235.
[8] Foster, Hammick, and Wardley, *J.*, 1953, 3817.

sodium carbonate solution, and finally dried and fractionated. The purity was checked spectroscopically. Other materials were purified by standard procedures.

Analytical. Full details of the method employed are given in an earlier paper.[1] It depends on the relation between the association constants, K' and K'', of two Lewis bases which are allowed to compete for one Lewis acid (or *vice versa*) in charge-transfer complex formation. If B′ and B″ are the two bases, then it may be shown that :

$$K' = \frac{D_0 - D_1}{D_1}\left(1 + \frac{[B'']K''}{[B']}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where D_0 is the optical density at, or near, the absorption maximum of the complex AB″, of a solution containing B″, at a concentration [B″], and A, at a concentration [A], where [A] $\ll$ [B″]. D_1 is the optical density at the same wavelength of a solution containing B″ at a concentration [B″], A at [A], and B′ at [B′], where [A] $\ll$ [B′]. If K'' is known, K' can be evaluated.

In the present work B″ is *NN*-diethylaniline. The value of K'' for the *NN*-diethylaniline–chloranil complex in *cyclo*hexane is 3·5 l./mole at 18—20°, between which temperatures all optical measurements were made. Data of a typical determination are given in Table 1.

TABLE 1. *Association constant* (K') *for hexamethylbenzene–chloranil in* cyclo*hexane solution. The symbols refer to the terms in equation* 3.

[B′] (M)	[B″] (M)	D_0	D_1	K' (l./mole)	K'' (l./mole)
0·1053	0·01122	0·287	0·235	3·5	27·0
0·1053	0·02245	0·287	0·203	3·5	25·2
0·1053	0·03370	0·287	0·180	3·5	24·2

Extrapolation of the plot of K'' against [B″] to the value [B″] = 0 results in a value of K'' = 28·6 l./mole.

The results of the determinations are summarised in Table 2. The extrapolated values of the association constant (K) are the average of at least three separate determinations. The second column gives values of the free energy of formation of the complexes referred to the standard state in which activity is equal to molarity at infinite dilution. Values of the wave-number of the centre of the charge-transfer band are given in the column headed ν.

TABLE 2. *Methylbenzene–chloranil complexes in* cyclo*hexane.*

	K (l./mole)	ΔG (cals./mole)	ν (cm.$^{-1}$)		K (l./mole)	ΔG (cals./mole)	ν (cm.$^{-1}$)
Benzene ...	0·56	+ 340	28,900	Durene	10·4	−1360	22,100
Toluene ...	1·7	− 310	27,400	Pentamethylbenzene	16·5	−1630	21,000
m-Xylene	2·9	− 613	25,600	Hexamethylbenzene	28·9	−1960	19,800
Mesitylene	5·9	−1030	24,500	Hexaethylbenzene...	1·3	− 152	too weak to be measured

Discussion.—Our results show that the free energy of interaction of chloranil with methylbenzenes up to hexamethylbenzene increases linearly in magnitude with the decreasing ionisation energies of the methylbenzenes.[9] Chloranil thus shows the same Lewis acid characteristics as *s*-trinitrobenzene[3] and iodine[4] in their interactions with these aromatic hydrocarbons (Fig. 1). The same order of free energy of interaction is shown in the iodine monochloride–methylbenzene complexes,[10] but here the linear correlation with the ionisation potentials of the benzene homologues is not very satisfactory. This relationship between the free energy of interaction and the ionisation potential of the methylbenzene may be expected if the interactions with which we are dealing are of charge-transfer type. The low value of the association constant of hexaethylbenzene–chloranil is almost certainly due to the steric interference of the ethyl groups hindering the approach of the chloranil molecule. This is the reason suggested for the corresponding low constant for the hexaethylbenzene–iodine association.[10,11]

[9] Franklin, *J. Chem. Phys.*, 1954, **22**, 1304.
[10] Andrews and Keefer, *J. Amer. Chem. Soc.*, 1952, **74**, 4500.
[11] Tamres, Vizi, and Searles, *ibid.*, 1953, **75**, 4358.

The energy of the excited state will mainly depend on the function $a^*\psi(A^- - B^+)$ in eqn. 2. This will be proportional, for a given Lewis acid, to the ionisation potential of the Lewis base. Consequently the energy of excitation of the complex may be expected to be a function of the ionisation potential of the electron donor. In fact, the mean energy of excitation represented by the centre of the charge-transfer band of each interaction (which

FIG. 1. *Relation between the ionisation potentials of methylbenzenes and the free energies of complex formation ($-\Delta G$) of these methylbenzenes with* (A) *chloranil in* cyclohexane, (B) *s-trinitrobenzene in carbon tetrachloride (see ref. 3),* (C) *iodine in carbon tetrachloride (see ref. 4).*

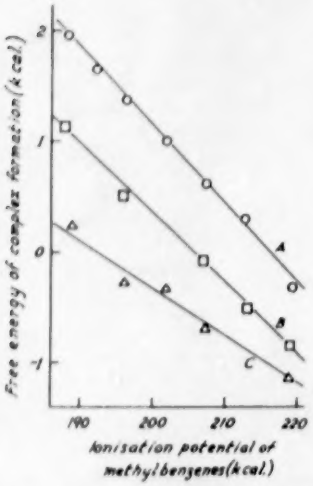
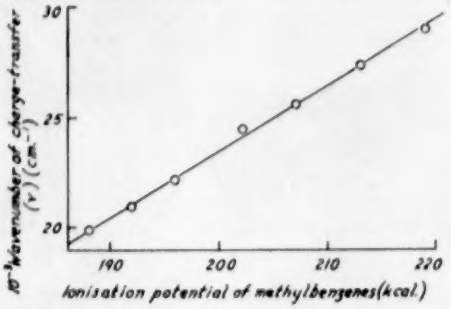


FIG. 2. *Relation between the ionisation potentials of methylbenzenes and the wave-numbers of the charge-transfer bands of the respective complexes with chloranil in* cyclohexane.



may consist of more than a single absorption) has been found to be directly proportional to the ionisation energy of the respective methylbenzenes (Fig. 2). A similar relation has been found for the methylbenzene–*s*-trinitrobenzene interactions by Briegleb and Czekalla,[3] and for electron donor–iodine interactions by McConnell, Ham, and Platt.[12]

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[12] McConnell, Ham, and Platt, *J. Chem. Phys.*, 1953, **21**, 66.

114. *Studies in Hydrogen-bond Formation. Part IV.* The Hydrogen-bonding Properties of Water in Non-aqueous Solution and of Alcohols, Aldehydes, Carbohydrates, Ketones, Phenols, and Quinones in Aqueous and Non-aqueous Solutions.*

By F. M. Arshid, C. H. Giles, and S. K. Jain.

By application of the refractive-index method of detecting complex formation in solution to over one hundred systems in various solvents the following conclusions are reached. The hydroxyl group in alcohols is monofunctional in hydrogen-bond formation and when present on vicinal carbon atoms in an aliphatic chain it forms weak five-membered chelate rings; consequently only one end-group in, *e.g.*, glycerol or mannitol, is normally available for intermolecular bonding. In aldehydes a variety of reactions demonstrate that the aldehyde group probably forms inter- and intramolecular bonds through its hydrogen atom.

In aqueous solutions of carbohydrates the open-chain form of glucose or cellobiose, in presence of certain other solutes, such as pyridine or amines, is stabilised by hydrogen-bond interaction of the aldehyde group; the hydroxy-groups are inactive because of solvation by water, though they are active in ethylene glycol solution. In aqueous solutions the hydroxy-groups are less reactive in the ring than in the open-chain forms of the simple carbohydrates and in the ring forms they do not combine with other solutes, even phenol. The bearing of these facts on the adsorption behaviour of cellulose is discussed.

The keto-group of ketones behaves bifunctionally and the quinone oxygen atom of quinones monofunctionally; ketones do not however form intermolecular complexes in benzene, ether, or water solutions. In non-aqueous solvents water appears to act either bifunctionally, probably by cross-linking, or monofunctionally in forming hydrogen-bond complexes with second solutes.

In Part II * the use of refractive-index measurements on solutions of binary mixtures of organic compounds to detect intermolecular or intramolecular complex-formation, principally of the hydrogen-bonding type, was described. The method has the advantage of being applicable to aqueous as well as to non-aqueous solutions. It was shown, both in theory and practice, that quite weak complexes can be readily detected, that the curves consist of virtually linear segments, intersecting at points corresponding to the molar ratio of the complex or complexes formed, and that forms of intermolecular association other than hydrogen-bonding can sometimes be detected. The nature of the bonds can, however, often be determined by inspection, when the complex-ratio is known.

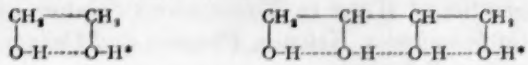
The present investigation, in which it is assumed that most of the complexes detected are attributable to hydrogen bonds, was designed to determine the hydrogen-bonding properties of water itself, and of hydroxyl groups, especially in carbohydrates; aldehydes and ketones were included as a knowledge of their properties is necessary for the interpretation of those of the carbohydrates. Table 1 summarises the results and typical curves are shown in Figs. 1—8. A discussion and suggested interpretations of the results follow. Some of the tests which were duplicated by the previously reported dielectric-constant method [1] are indicated.

Alcohols.—The hydroxyl group appears to be normally monofunctional in the alcohols, one molecule of, for example, phenol combining with each such group in methanol (Fig. 2), ethanol, *n*-butanol, *n*-pentanol, ethylene glycol, glycerol, erythritol, or mannitol. In each of the polyhydric alcohols, however, an additional 1 : 1-complex is formed with phenol; and with methanol (Fig. 2), triethylamine, or water no other complex but that of 1 : 1 ratio is evident. The most reasonable interpretation of these observations seems to

* Parts II and III, *J.*, 1955, **67**; 1956, 72.

[1] Giles, Rose, and Vallance, *J.*, 1952, 3799.

be that pairs of vicinal hydroxyl groups interact to form weak five-membered chelate rings, *e.g.*, in ethylene glycol or a carbohydrate chain :



This leaves in each polyhydric alcohol only one hydrogen atom (starred) free to form intermolecular bonds (in a suitable solvent) with a weak second solute such as methanol. Phenol, however, being a more powerful hydrogen-bonding agent, can disrupt these rings in some of the molecules and so unite with each hydroxyl group.

TABLE 1. (*For footnotes, see p. 562.*)

Solutes		Solution.			
a	*b*	Solv.*	Total mol. concn.	Method † and temp.	Mol. ratio of complex (*a* : *b*) ‡
Alcohols					
Methanol	Phenol	D	0·1	*n* 20°	1 : 1
		W	0·25	*n* 20	1 : 1
Ethanol	Water	D	0·1	ε, *n* 20	1 : 1
,,	Phenol	T	0·25	ε, *n* 19	1 : 1
		W	0·25	*n* 20	1 : 1
*iso*Butanol	Phenol	D	0·1	*n* 21	1 : 1
n-Pentanol	,,	D	0·1	*n* 21	1 : 1
Ethylene glycol	Methanol	D	0·1	*n* 20	1 : 1
,,	Phenol	D	0·1	*n* 19	1 : 1; 1 : 2
,,	Triethylamine	W	0·2	*n* 19·7	1 : 1
		W	0·25	*n* 20	1 : 1; (1 : 2)
Glycerol	Methanol	D	0·1	*n* 20	(1 : 1)
		W	0·25	*n* 20	§
,,	Phenol	W	0·25	*n* 20	1 : 1; 1 : 3
,,	Triethylamine	W	0·1	*n* 20	1 : 1
,,	Water	D	0·1	*n* 20	1 : 1
Erythritol	Methanol	W	0·25	*n* 21	§
,,	,,	Cs	0·05	*n* 18	1 : 1
,,	Phenol	W	0·25	*n* 19	1 : 1; 1 : 4
Mannitol	,,	W	0·25	*n* 19	1 : 6
,,	Water	EG	0·1	*n* 18	1 : 1
,,	Phenol	EG	0·1	*n* 22	(1 : 1); 1 : 6
Butane-1 : 4-diol	Methanol	D	0·1	*n* 15·5	§
,,	Phenol	D	0·1	*n* 16·5	§
Pentane-1 : 5-diol	Methanol	D	0·1	*n* 18	1 : 2
,,	Triethylamine	W	0·2	*n* 19·7	1 : 2
Aldehydes					
Acetaldehyde	Azobenzene	T	0·1	*n* 20	2 : 1
,,	Diethylamine	W	0·25	*n* 20	1 : 1
,,	Ethanol	W	0·25	*n* 20	§ **
,,	Phenol	W	0·25	*n* 20	(§)
Formaldehyde	Phenol	W	0·2	*n* 20	§
,,	Triethylamine	W	0·2	*n* 20	1 : 1
m-Nitrobenzaldehyde	Phenol	T	0·2	*n* 21	1 : 1; 1 : 3
,,	Pyridine	T	0·1	*n* 21	1 : 1
,,	Triethylamine	T	0·2	*n* 21	1 : 1
o-Nitrobenzaldehyde	Phenol	T	0·1	*n* 19	1 : 2
,,	Pyridine	T	0·1	*n* 21	§
,,	Triethylamine	T	0·1	*n* 19	§
Propionaldehyde	Diethylamine	B	0·2	*n* 15	1 : 1; (1 : 2)
,,	Dimethylformamide	C	0·2	*n* 18	1 : 1
,,	,,	W	0·2	*n* 18	1 : 1
,,	Ethanol	C	0·2	*n* 17·5	1 : 1
,,	,,	W	0·2	*n* 17·5	(§)
,,	Phenol	C	0·1	*n* 17	(1 : 1)
,,	,,	EG	0·2	*n* 18	1 : 1
,,	,,	W	0·2	*n* 17·5	§
,,	Pyridine	D	0·2	m.w.	1 : 1
,,	,,	W	0·2	*n* 17·5	1 : 1
,,	Triethylamine	W	0·2	*n* 17·5	1 : 1
Terephthalaldehyde	Triethylamine	T	0·2	*n* 18	1 : 2
,,	,,	W	0·1	*n* 17	1 : 2

TABLE 1. (*Continued.*)

Solutes		Solution.			
a	*b*	Solv.*	Total mol. concn.	Method † and temp.	Mol. ratio of complex (*a* : *b*) ‡
Carbohydrates					
D-Cellobiose	Aniline	W	0·25	*n* 16°	1 : 1
,,	Azobenzene-4-sulphonic acid	W	0·1	*n* 22	(2 : 1)
,,	Diethylamine	W	0·25	*n* 19	(1 : 1)
,,	Dimethylformamide	W	0·25	*n* 15	1 : 1
,,	Pyridine	W	0·1	*n* 18	1 : 1
,,	Quinol	W	0·25	*n* 16	(§)
,,	Triethylamine	W	0·25	*n* 15	(1 : 1)
D-Fructose	Ethanol	W	0·25	*n* 20	(§)
,,	Phenol	W	0·25	*n* 21	(§)
,,	Triethylamine	W	0·25	*n* 20	(§)
D-Glucose	Acetamide	W	0·25	*n* 22	1 : 1
,,	Aniline	W	0·25	*n* 18	2 : 1
,,	Azobenzene-4-sulphonic acid	W	0·1	*n* 19	(2 : 1)
,,	Diethylamine	W	0·25	*n* 19	1 : 1
,,	Dimethylformamide	W	0·25	*n* 18	1 : 1
,,	Ethanol	W	0·25	*n* 20	§
,,	Methanol	W	0·25	*n* 20	§
,,	*p*-Nitrophenol	W	0·10	*n* 18	1 : 1
,,	Phenol	W	0·25	*n* 20, 35; m.w.	§
,,	,,	Buffer pH 8·4	0·2	*n* 17·5	§
,,	,,	EG	0·1	*n* 20	1 : 6
,,	Pyridine	W	0·25	*n* 19	(1 : 1)
,,	Triethylamine	W	0·25	*n* 20	1 : 1
,,	Quinol	W	0·25	*n* 17	§
,,	Urea	W	0·2	*n* 15	§
,,	,,	W	2·0	*n* 16	§
,,	Water	EG	0·1	*n* 14	1 : 6; (2 : 1)
Sucrose	Triethylamine	W	0·25	*n* 20	§
2 : 3 : 4 : 6-Tetra-*O*-methylgluco-pyranose	Water	D	0·05	*n* 20	2 : 1; 1 : 2
Solutions of ternary mixtures					
D-Glucose (1 mol.) + Pyridine (1 mol.)	Phenol	W	0·1	*n* 19	1 : 6
		W	0·2	m.w.	1 : 6
D-Glucose (1 mol.) + Triethylamine (1 mol.)	,,	W	0·1	*n* 13	1 : 1; 1 : 6
Ketones					
Acetone	Aniline	B	0·3	ε	§
,,	Diethylamine	B	0·2	ε	§
,,	Phenol	E	0·25	*n* 20	§
,,	,,	W	0·1	*n* 20	§
,,	Methanol	C	0·25	*n* 20	(1 : 2)
	,,	D	0·05	*n* 17	1 : 2
,,	Propionaldehyde	T	0·2	*n* 20	1 : 1
,,	Triethylamine	W	0·25	*n* 21	§
,,	Quinol	E	0·25	*n* 18	§
Benzophenone	Phenol	B	0·25	*n* 18	§ ¶
Di*iso*butyl ketone	Phenol	D	0·25	ε, *n* 20	1 : 2
Quinones					
2 : 3-Benz-9-anthrone	*N*-*n*-Butylpropionamide	D	0·01	*n* 20	1 : 2
,,	Phenol	D	0·01	*n* 20	1 : 1 ‖
Benzoquinone	Anisole	D	0·1	*n* 20	1 : 2
,,	*N*-*n*-Butylpropionamide	T	0·2	ε, *n* 20	1 : 4 ‖
,,	Phenol	T	0·25	ε, *n* 19	(1 : 2)
Phenols					
Catechol	Methanol	D	0·1	*n* 15·5	1 : 1
,,	Phenol	D	0·2	*n* 16	(1 : 1; 1 : 2)
Pyrogallol	Phenol	W	0·25	*n* 20	(1 : 1); 1 : 3
Quinol	Methanol	D	0·1	*n* 20	(1 : 2)
,,	Phenol	W	0·25	*n* 19	1 : 2

TABLE 1. (*Continued.*)

Solutes		Solution.			
a	*b*	Solv.*	Total mol. concn.	Method † and temp.	Mol. ratio of complex (*a* : *b*) ‡
Water					
Water	Acetone	D	0·2	*n* 20°	1 : 1; 2 : 1
"	Aniline	D	0·25	ε, *n* 20	(2 : 1)
"	Aniline → 2-naphthol	D	0·1	ε, *n* 20	1 : 2
"	Azobenzene	D	0·1	ε, *n* 20	1 : 1; 2 : 1
"	Benzophenone	D	0·2	ε, *n* 20	(1 : 2)
				n 17	1 : 2
"	*N*-*n*-Butylpropionamide	D	0·2	ε, *n* 20	1 : 2 ‖
"	Di*iso*butyl ketone	D	0·1	ε, *n* 20	1 : 1
				n 17	1 : 1 ‖
"	Phenol	D	0·2	*n* 20	1 : 1; 1 : 2
"	Propionaldehyde	EG	0·2	*n* 17	1 : 1
"	Styrene	D	0·2	*n* 20	1 : 2 ‖

* *Solvents*: B = benzene; C = carbon tetrachloride; Cs = "Cellosolve" (2-ethoxyethanol); D = dioxan; E = diethyl ether; El = ethanol; EG = ethylene glycol; T = toluene; W = water.
† *Methods*: ε = dielectric constant; *n* = refractive index; m.w. = apparent mol. wt.
‡ Data in parentheses denote uncertain indications.
§ No evidence of complex formation.
‖ These curves show particularly pronounced change of slope.
¶ Results by dielectric-constant method reported in Part I.[1]
** In Part II (*J.*, 1955, 67) Table 1, column 3, lines 1 and 2, *for* W *read* C.

Bastiansen [2] detected this form of intramolecular bond in ethylene glycol and glycerol by the electron-diffraction sector method, and pointed out that published heats of combustion confirm its presence, being for these compounds, respectively, 5·4 and 10·3 kcal./mole lower than required by theory, *i.e.*, less by about the values for one and two hydrogen bonds, respectively.

Further confirmation of the existence of this bond was obtained by the examination of a diol in which the pairs of alcoholic groups are too widely separated to react intramolecularly. Thus, in pentane-1 : 5-diol (Fig. 2) both groups are free to react intermolecularly and a 1 : 2-complex is formed with methanol. Butane-1 : 4-diol did not appear to form intermolecular complexes; possibly a seven-membered ring is present, but even this would not explain the complete unreactivity.

A similar intramolecular bond to that in the polyhydric alcohols has been detected between the *ortho*-hydroxyl groups in catechol by infrared spectroscopic examination of its carbon tetrachloride solution; [3] in the present work its existence is evident in the 1 : 1-complex formed between catechol and phenol, though the inflexions of the curves are not very clear.

TABLE 2. *Physical constants of certain chelated and unchelated compounds.*

Chelated	M. p.	B. p.	Unchelated	M. p.	B. p.
Alcohols and phenols					
Catechol	104°		Quinol	169°	
Butane-1 : 2-diol	—	191°	Butane-1 : 3-diol	—	203°
Butane-2 : 3-diol	—	183	Pentane-1 : 4-diol	—	219
Pentane-2 : 3-diol	188	—	Pentane-1 : 5-diol	—	238
			Pentane-2 : 4-diol	—	197
Nitro-compounds					
o-Nitrophenol	44	—	*p*-Nitrophenol	114	—
o-Nitrobenzoic acid	144	—	*p*-Nitrobenzoic acid	241	—
o-Nitrobenzaldehyde	44	—	*p*-Nitrobenzaldehyde	106	—

The m. p.s or b. p.s of certain diols (Table 2) also give evidence of chelation, the compounds with vicinal groups having lower values than the corresponding isomers with more widely separated groups. This is also evident with catechol and quinol.

Aldehydes.—The aldehyde group is monofunctional towards all the second solutes used, except ethanol or phenol in water, where the solvent prevents interaction; both aldehyde

[2] Bastiansen, *Acta Chem. Scand.*, 1949, **3**, 415.
[3] Wulf, Liddel, and Hendricks, *J. Amer. Chem. Soc.*, 1936, **58**, 2287.

groups are reactive in the only dialdehyde tested (terephthalaldehyde, Fig. 4). There seems no doubt of the reality of the complexes formed with hydrogen-acceptors (pyridine, triethylamine), both by reason of the variety of reactions in which they are evident (including those of the carbohydrate mixtures discussed on p. 567) and the evidence given by molecular-weight experiments (Figs. 3 and 8). The most likely interpretation

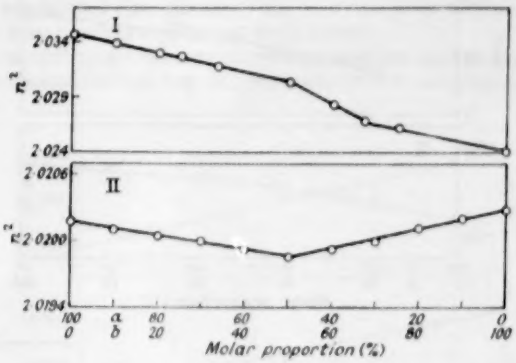


FIG. 1. *Relation between the square of the refractive index and the component ratio in solutions of binary mixtures containing water.*

I: *a*, Azobenzene; *b*, water. Solvent: dioxan.

II: *a*, Diisobutyl ketone; *b*, water. Solvent: dioxan.

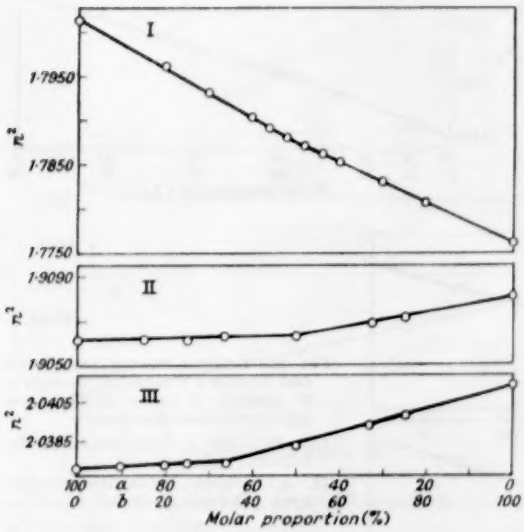


FIG. 2. *Relation between the square of the refractive index and the component ratio in solutions of binary mixtures containing methanol.*

I: *a*, Phenol; *b*, methanol. Solvent: water.

II: *a*, Methanol; *b*, erythritol. Solvent: 2-ethoxyethanol.

III: *a*, Methanol; *b*, pentane-1 : 5-diol. Solvent: dioxan.

of the results is that the interaction is by bonding with the hydrogen atom of the aldehyde group,* which is activated by the carbonyl oxygen. The bond is thus somewhat similar to that in the hydrogen cyanide crystal: [4]

* The reactions cannot be attributed to the presence of carboxylic acid formed by oxidation of the aldehyde by air, because of the infrared evidence (see Experimental section) that acid is not formed appreciably in presence of the hydrogen acceptor.

[4] Pauling, "The Nature of the Chemical Bond," Cornell Univ. Press, Ithaca, New York, 1944, 2nd edn., pp. 294—295.

Dipole-interaction effects produced by hyperconjugation of the attached alkyl group [5] cannot be responsible for these complexes because formaldehyde behaves like its higher homologues. The nature of the complexes formed by phenol or pyridine with nitrobenzaldehydes (Fig. 5) (cf. those between phenol and nitrophenols or nitrobenzene [6]) seems

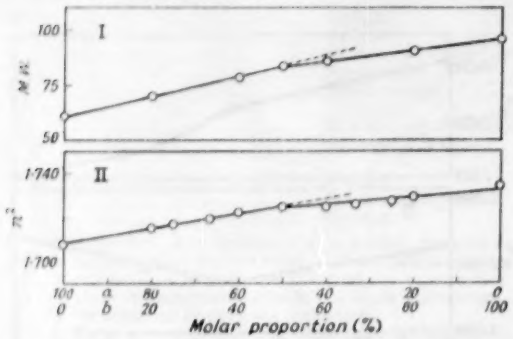
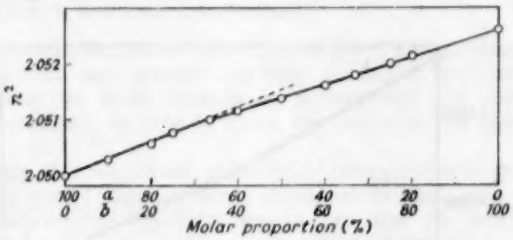


FIG. 3. *Relation between the molar ratio, square of the refractive index, and apparent molecular weight in solutions of binary mixtures containing propionaldehyde.*

a, Propionaldehyde; *b*, pyridine. Solvent: I, dioxan; II, water.

FIG. 4. *Relation between molar ratio and the square of the refractive index in solutions of binary mixtures containing a dialdehyde.*

a, Triethylamine; *b*, terephthalaldehyde. Solvent: dioxan.



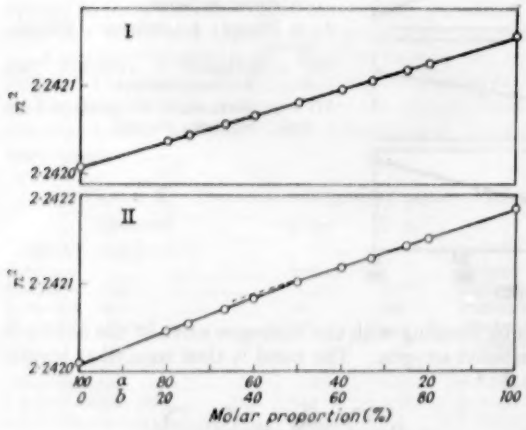


FIG. 5. *Relation between molar ratio and the square of the refractive indexes in solutions of binary mixtures containing nitrobenzaldehydes.*

I: *a*, Pyridine; *b*, *o*-nitrobenzaldehyde. Solvent: toluene.

II: *a*, Pyridine; *b*, *m*-nitrobenzaldehyde. Solvent: toluene.

to indicate that the hydrogen atom of the aldehyde group can form intra- as well as inter-molecular bonds. Lundgren and Binkley,[7] using Rhodamine B (Colour Index No. 749) as a hydrogen-donor indicator (colourless in a hydrocarbon, becoming red in

[5] Coulson, "Valence," Clarendon Press, Oxford, 1952, p. 311.

[6] Part II, Arshid, Giles, McLure, Ogilvie, and Rose, *J.*, 1955, 67; Part III, Arshid, Giles, Jain, and Hassan, *J.*, 1956, 72.

[7] Lundgren and Binkley, *J. Polymer Sci.*, 1954, **14**, 139.

presence of a hydrogen donor, *e.g.*, water or phenol), noticed that *o*-nitrobenzaldehyde exhibits little activity towards the dye, compared with the activity of the ***meta***-isomer, and they attributed the difference to chelation in the *ortho*-compound. In the present work propionaldehyde in dry toluene gave a positive reaction with the dye (even after being kept over sodium hydrogen carbonate to remove traces of carboxylic acid).

The chelate ring in *o*-nitrobenzoic acid and *o*-nitrophenol gives these compounds a m. p. much lower than that of their unchelated *para*-isomers; the lower m. p. of *o*-nitrobenzaldehyde than of the ***meta***-isomer may thus likewise be due to chelation.

The results of some infrared spectroscopic measurements on various mixtures containing aldehydes are described in the Experimental section, but unfortunately give no conclusive

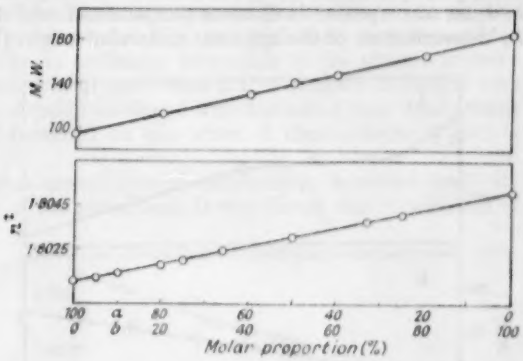


FIG. 6. *Relation between molar ratio, square of refractive index at 20°, and apparent molecular weight of solutions of binary mixtures*

a, Phenol; *b*, glucose. Solvent: water.

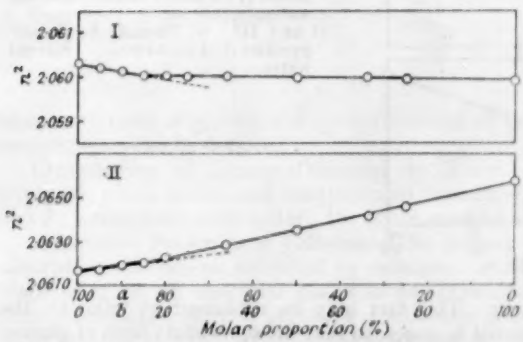


FIG. 7. *Relation between square of refractive index and component ratio in solutions of binary mixtures.*

I: *a*, Phenol; *b*, glucose. Solvent: ethylene glycol.

II: *a*, Water; *b*, glucose. Solvent: ethylene glycol.

evidence for or against the present hypothesis that the aldehydic hydrogen atom is active in hydrogen bonding.

[Evidence of interaction between aliphatic aldehydes and alcohols in binary liquid mixtures, interpreted as being due to hemiacetal formation, is given by refractive-index measurements [8] (1 : 1-complexes in several examples) and by infrared spectroscopy.[9]]

Carbohydrates.—The reactions of glucose and cellobiose in water (Table 1) show that they each behave monofunctionally towards reactive second solutes and that their reactions are identical with those of aliphatic aldehydes. It is, therefore, assumed that these carbohydrate molecules react through the aldehyde group in their open-chain forms, and not as the pyranose ring structures. The normal equilibrium state of glucose in water is strongly in favour of the α- and β-ring structures, only a small percentage of the open-chain aldehyde being present. If, however, in the equilibrium mixture the aldehyde group

[8] Adkins and Broderick, *J. Amer. Chem. Soc.*, 1928, **50**, 499.
[9] Ashdown and Kletz, *J.*, 1948, 1454.

alone can form an intermolecular bond with, for example, pyridine or triethylamine (the hydroxy- and ether groups probably being protected by the water), then complex-formation will disturb the equilibrium, causing more open-chain compound to form, and sufficient of the intermolecular complex must ultimately be produced to affect perceptibly the curves examined. If this is so, triethylamine in water should be unable to form complexes, *e.g.*, with the ketoses, and, in fact, none is detected with either fructose or sucrose.

The non-reactivity of the hydroxy-groups of the carbohydrates towards most other solutes is consistent with other evidence (Table 1) of their behaviour in water, but the non-reactivity of phenol with glucose and with cellobiose is unexpected because phenol does normally combine with alcoholic groups in water, even with each such group in a straight-chain polyhydric alcohol, *e.g.*, mannitol. The experiment with glucose and phenol (Fig. 6) in water was repeated at different temperatures, and the result was checked and confirmed by determination of the apparent molecular weight (Fig. 6); there thus appears to be no

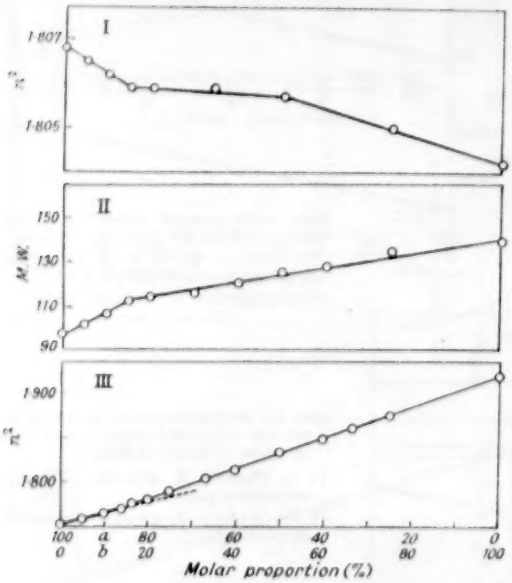


FIG. 8. *Relation between molar ratio, square of refractive index, and apparent molecular weight in solutions of ternary mixtures containing glucose.*

I : *a*, Phenol; *b*, glucose–triethylamine (1 : 1 molar ratio). Solvent: water.

II and III : *a*, Phenol; *b*, glucose–pyridine (1 : 1 molar ratio). Solvent: water.

doubt that interaction does not occur. This fact may be explained as follows: the aldehyde group is inactive towards phenol in water, so that the open-chain form of glucose will not, following the argument above, be stabilised by phenol. It follows that the inactivity of glucose hydroxy-groups towards phenol in water is a property of the ring form. It seems likely, in fact, that the water-attracting power of the hydroxy-groups is greater in the ring than in the open-chain form. Models demonstrate that the solvated water molecules on opposite sides of the glucose molecule must be closer together at their nearest distance, and so must experience greater mutual attraction, in presence of the ring form than in presence of the open-chain form in its most probable crumpled state. (The shortest distances of separation are about 4 and 6·5 Å respectively.) This increased affinity of the surrounding water must stabilise the ring structure and act as a protective atmosphere against weak interaction with other solutes.* Its stabilising action would also account

* [*Added, October* **16***th*, **1955**.] A detailed study of the thermodynamic properties of glucose solutions has been published by Taylor and Rowlinson (*Trans. Faraday Soc.*, 1955, **51**, 1183) in which they find that both glucose and sucrose solutions "show negative excess heats, entropies, free energies, and volumes, indicating that there is strong hydrogen-bonding between the sugars and the surrounding water molecules. This bonding is apparently stronger, or more abundant, than that between the water molecules themselves."

for the ring structures' being favoured in water, instead of the more statistically probable open-chain form.

Confirmation of this hypothesis was obtained by the examination of solutions in ethylene glycol, and the use of certain solutions of ternary mixtures, as follows.

(*a*) *Solutions in ethylene glycol.* The alcoholic chelate rings persist in this solvent (see mannitol, Table 1) and its use should show whether the non-reactivity of the glycosidic groups in water may be due to chelation. 1 : 6-Complexes are formed between glucose and either phenol or water in this solvent (Fig. 7), so that the groups must be unchelated.

(*b*) *Use of solutions of ternary mixtures.* On the above arguments the addition of pyridine or triethylamine to an aqueous solution of a binary mixture of glucose and phenol should stabilise the open-chain glucose molecule and enable each of its hydroxy-groups to combine with phenol. Accordingly refractive-index measurements were made on two series of glucose–phenol solutions of constant molarity, to which there had been added pyridine and triethylamine respectively, in equimolar proportion to the glucose in every solution. The results (Fig. 8) confirm that in both cases a 1 : 6-complex is formed with phenol (the sixth phenol molecule is probably combined with the added base itself). The apparent molecular-weight curve, determined on one series of these solutions, gave a similar result (Fig. 8).

In confirmation that these complexes are not formed merely by an increased reactivity of phenol produced by the alkalinity of the added base, it was shown that in solutions of

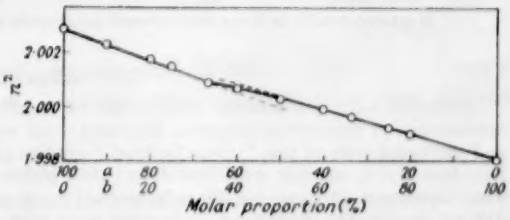


FIG. 9. *Relation between the square of the refractive index at 17·5° and component ratio in solutions of binary mixtures* (cf. Fig. 5 and footnote, *J.*, 1955, 70, in Part II [9]).

a, Resorcinol; *b*, diethylamine. Solvent: dioxan.

binary mixtures of glucose and phenol buffered at the pH (8·4) of the pyridine solutions, no complexes can be detected.

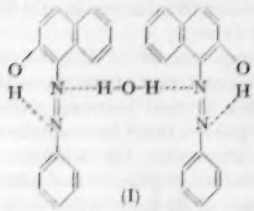
Cross-linking of Glucose Derivative by Water.—Examination of tetramethylglucopyranose, which retains one unsubstituted hydroxy-group, shows that it forms both 1 : 2- and 2 : 1-complexes with water; the latter must be a cross-linked compound.

Adsorption Properties of Cellulose.—The present work helps to explain some of the adsorption phenomena exhibited by cellulose. Adsorption on this substrate must take place, if at all, on molecular chains in non-crystalline regions, and in aqueous solutions these presumably resemble glucose and cellobiose in being surrounded by an atmosphere of water molecules bound so firmly that other solutes cannot normally penetrate it. It seems clear, therefore, that in presence of excess of water cellulose does not normally adsorb solutes by hydrogen bonding. This explains why phenol, which is readily absorbed from dilute aqueous solution by fibrous substrates capable of hydrogen bonding, *e.g.*, nylon, wool,[10] and cellulose acetate,[11] is entirely unadsorbed under similar conditions by regenerated cellulose [11] or cotton.[12] Preston and Nimkar [13] by studying freezing-point curves of adsorbed moisture in cellulose fibres, have shown that the non-crystalline parts of the fibre are in a state resembling solution in the water, so they should behave as glucose.

Ketones.—The few tests so far made point to the ketone group's being bifunctional in combination with alcohols or phenols; it is inactive towards all other solutes in benzene, ether, or water, and there is no evidence that ketones can act as hydrogen-donors.

[10] Chipalkatti, Giles, and Vallance, *J.*, 1954, 4375.
[11] Marsden and Urquhart, *J. Textile Inst.*, 1942, **33**, T105.
[12] Giles, Jain, and Hassan, *Chem. and Ind.*, 1955, 629.
[13] Preston and Nimkar, *Textile Res. J.*, 1953, **23**, 119.

Quinones.—2 : 3-Benz-9-anthrone was included to test the reactivity of a single quinone oxygen atom; this reacts apparently as do the individual oxygen atoms in normal quinones which each combine with one phenolic group or with two amide groups.



(I)

Water.—Used as a solute, water can act either monofunctionally or bifunctionally, presumably as a cross-linking agent, both hydrogen atoms being involved in bonds (cf. Fig. 1) *e.g.*, with 1-phenylazo-2-naphthol * as in (I). In the styrene–water 2 : 1-complex one of the hydrogen atoms of the double bond of each styrene molecule must be involved in a bond with the oxygen of the water.

Solvent-protection.—For convenience, the examples already discussed of the prevention of intermolecular bonding by solvation are summarised in Table 3.

TABLE 3. *Solvation effects in intermolecular hydrogen bonding.*

Groups		Solvent (see Table 1)	
a	*b*	*a* Reactive with *b* in	Inactive in
OH (alk)	OH (alk)	Cs, D	W
"	OH (ar)	T, W	None
OH (ar)	OH (ar)	D, T, W	None
CHO (alk; ar)	OH (alk, ar)	C, T	W
"	$\cdot N_3$, $\cdot NR_3$, etc.	All	None
C=O (keto)	All	C, D, T	B, E, W

Negative results in these tests are not necessarily conclusive (cf. Parts II [8] and III [9]).

EXPERIMENTAL

Materials.—All compounds were either of Analytical Reagent quality or were purified commercial or laboratory-prepared products. All solvents were completely dried. Dioxan and methanol were of the " specially dried " quality (B.D.H.) used for Karl Fischer titrations. Ethylene glycol was first fractionated and then passed through activatedalumina. 2 : 3-Benz-9-anthrone was prepared by Fieser's method [15]; it formed buff crystals, m. p. 176°. As it did not couple with diazonium solutions it must exist as the ketone. The preparation of *N*-*n*-butylpropionamide was described in Part I.[1] Formaldehyde was prepared by heating paraformaldehyde, collecting the gas in water, and determining its concentration volumetrically by oxidation with hydrogen peroxide in presence of sodium hydroxide.

Infrared Spectroscopy.—The following were examined : (i) solutions in carbon tetrachloride of (*a*) phenol (0·1M), (*b*) pyridine (0·1M), (*c*) propionaldehyde (0·1M), (*d*) phenol (0·05M) and propionaldehyde (0·05M), (*e*) pyridine (0·05M) and propionaldehyde (0·05M), and (ii) (*f*) *iso*butyraldehyde (pure) and (*g*) an equimolar mixture of *iso*butyraldehyde and pyridine. There was evidence of a small increase in hydrogen bonding of the phenolic group in (*d*), the optical densities of the free and bonded OH-stretching frequencies of phenol alone (0·1M) being 0·505 and 0·097 respectively, and of phenol (0·05M) in presence of propionaldehyde, 0·0315 and 0·105, respectively. The bonded OH band also broadened and shifted slightly from 3460 cm.$^{-1}$ to 3440 cm.$^{-1}$. In the mixed solutions or mixtures containing pyridine, the indications were inconclusive; thus the pyridine–propionaldehyde curve could not be properly evaluated owing to the presence of some propionic acid in the propionaldehyde reference spectrum, evidently arising from aerial oxidation, though little or no acid was evident in the mixture itself; and in the *iso*butyraldehyde–pyridine mixture there also appeared to be traces of carboxylic acid, which interfered with examination of the aldehyde bands; slight shifts actually observed in these were not considered significant.

This, however, does not constitute evidence of non-interaction, because even in the phenol–aldehyde solution, in which interaction is demonstrable, there was no evidence of changes in the characteristic bands of the aldehyde group; and moreover, whereas the solution of aldehyde alone gave evidence of the presence of very little free carboxylic acid produced by aerial

* Brode, Sheldin, Spoerri, and Wyman [14] have attributed the appearance of a new band in the light-absorption spectra of alcoholic solutions of certain azo-compounds, on addition of water, to a hydrogen bond between the azo-group and water.

[14] Brode, Sheldin, Spoerri, and Wyman, *J. Amer. Chem. Soc.*, 1955, **77**, 2762.
[15] Fieser, *ibid.*, 1931, **53**, 2329.

oxidation, free acid was detected in either of the mixed solutions (*d*) or (*e*). Whatever the reason for this may be, it seems conclusive that pyridine influences the aldehyde group chemically.

The spectroscopic results therefore give no decisive evidence either for or against the hypothesis of bonding by the hydrogen of the aldehyde group.

Instruments and Procedure.—These have already been described in Parts I [1] and II; [6] a Bellingham and Stanley Pulfrich refractometer was also used in many of these experiments of this work. Infrared spectra were recorded in 1 mm. cells (solutions) on a Perkin-Elmer Model 13 instrument or in 0·05 and 0·025 mm. cells (pure liquids) on a Grubb-Parsons instrument, both with sodium chloride prism.

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115. *Organic Complex-forming Agents for Metals. Part I. Preparation of 4-Hydroxy- and 4 : 7-Dihydroxy-benziminazoles and Related Compounds.*

By E. S. LANE and C. WILLIAMS.

Methods are detailed for the synthesis and characterisation of 4-hydroxy-, 4 : 7-dihydroxy-, and 4 : 7-dihydroxy-1-methyl-2-substituted benziminazoles. Syntheses of 4-hydroxy-benzoxazoles, -benzotriazoles, and -benzo-2 : 1 : 3-selenadiazoles are included.

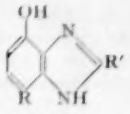
4-HYDROXYBENZIMINAZOLE (I; R = R′ = H) was first synthesised by Sorkin, Roth, and Erlenmeyer,[1] and substituted compounds of this type were later described by Gillespie and Graff.[2] These compounds were required for biological examination, and their analytical applications have not been reported. This paper reports the preparation of a series of compounds based on, and including, 4-hydroxybenziminazole and it is hoped to examine their analytical behaviour especially in view of the manifold application of the somewhat similar 8-hydroxyquinoline and its substituted derivatives.

The chelating system, 4-hydroxybenziminazole, is of interest from a theoretical viewpoint since considerable modification of the basicity of the tertiary nitrogen atom of the benziminazole ring system can be effected by varying the substituent in the 2-position.[3] Furthermore, the corresponding 4 : 7-dihydroxybenziminazoles (I; R = OH) are of interest since the additional possibility exists of metals forming a complex with the 1-hydrogen atom and the 7-hydroxyl group. Some members of this series have been synthesised including some where a methyl group has been inserted in the 1-position to remove complex-forming power from that position. The corresponding 4-hydroxybenzoxazoles (II; R = H, Me), -benzotriazole (III), and -benzo-2 : 1 : 3-selenadiazole (IV; R = OH), which possess essentially the same complex-forming groups, but with different relative donor and acceptor properties, have also been synthesised.

The benziminazoles were prepared by Phillips's method [4] from a variety of acids and

[1] Sorkin, Roth, and Erlenmeyer, *Helv. Chim. Acta*, 1952, **35**, 1736.
[2] Gillespie and Graff, *J. Amer. Chem. Soc.*, 1954, **76**, 3531.
[3] Lane, *J.*, 1955, 534; Belcher, Sykes, and Tatlow, *J.*, 1954, 4159.
[4] Phillips, *J.*, 1928, 2397.

2 : 3-diaminoanisole, 2 : 3-diaminoquinol diethyl ether, and 2-amino-3-methylaminoquinol diethyl ether, respectively. The last base had been prepared by Nelson and Brown's alkylation method[5] from the unsubstituted base and methyl iodide. Perfluoroalkyl groups and lower alkyl groups were introduced into the 2-position, the object being first to decrease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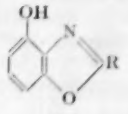
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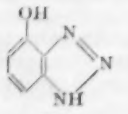
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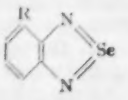
(IV)

and then to increase the basicity of the tertiary nitrogen atom. With the exception of the perfluoroalkyl derivatives these benziminazoles were all basic compounds, forming well-defined salts with dilute acids; their properties are detailed in the Tables. The chemical behaviour of the perfluoroalkyl derivatives was appreciably different from that of the unsubstituted analogues. Whereas the alkylbenziminazoles were smoothly demethylated with anhydrous aluminium chloride in boiling benzene, concentrated hydrobromic acid gave better yields from the perfluoro-compounds. Mineral acid salts formed by the latter were hydrolysed by water to the parent base, indicating a considerably weakened basic nitrogen atom. All the 4-hydroxy-benziminazoles were stable in air, but with the exception of the perfluoro-derivatives the 4 : 7-dihydroxy-benziminazoles were obtained only as salts. 4 : 7-Dihydroxybenziminazole, obtained on basification of a solution of its hydrochloride, was rapidly oxidised on exposure to air. No further attempt was made to prepare the free higher homologues, since with increasing basicity the instability is also likely to increase. The characterisation of these hydroxy-benziminazoles was attempted by the formation of their acetates. The 4 : 7-dihydroxy-series formed normal diacetates with pyridine and acetic anhydride. Of the 4-hydroxy-benziminazoles only the perfluoroalkyl-derivatives gave stable products; others gave unstable crystalline compounds of indeterminate constitution, which evolved acetic acid and left a gum on storage. The compound formed from 4-hydroxybenziminazole was 4(7)-acetoxy-1-acetylbenziminazole.

The corresponding hydroxy-benzoxazoles, -benzotriazoles, and -benzo-2 : 1 : 3-selenadiazoles were prepared by extensions of known reactions. In the dealkylation of 4-methoxy-[6] and 4 : 7-diethoxy-benzo-2 : 1 : 3-selenadiazoles by anhydrous aluminium chloride in benzene, the former compound was recovered unchanged after refluxing with 1 mol. of aluminium chloride, but use of 2 mols. gave the required hydroxy-compound in high yield. When 4 : 7-diethoxybenzo-2 : 1 : 3-selenadiazole was similarly treated with 2 mols. of aluminium chloride only one ethoxy-group was de-ethylated. When 3 mols. were used a very easily oxidizable compound, believed to be the 4 : 7-dihydroxy-derivative, was obtained, but was too labile for isolation and characterisation. Both this compound and the 4 : 7-dihydroxy-benziminazoles described above would be expected to form the corresponding *p*-quinone on oxidation. It appears that in the dealkylation 1 mol. of aluminium chloride is rendered unavailable owing to co-ordination to the selenium atom which, in the conventional formulation of benzo-2 : 1 : 3-selenadiazoles (IV), is co-ordinatively unsaturated.

Experimental

Determination of the Equivalent Weight of Benziminazoles and Related Substances.—Two methods were used: (*a*) Titration with perchloric acid in glacial acetic acid, (i) crystal-violet or (ii) a high-frequency conductometric procedure[6] being used for determination of the end-point; (*b*) titration with sodium methoxide in methanol–benzene with ethylenediamine as solvent and the high-frequency conductometric end-point procedure. Some compounds were suitable for determination by both methods; letters in parentheses below indicate which method was used.

Preparation of Perchlorates for Characterisation.—Base perchlorates were obtained by adding slightly more than 1 equiv. of 0·1N-perchloric acid in glacial acetic acid to the base in solution

[5] Nelson and Brown, *J. Amer. Chem. Soc.*, 1953, **75**, 24.
[6] Lane, *Analyst*, 1955, **80**, 675.

in the same solvent. Precipitation of the salt was completed by addition of light petroleum. For results see Table 1.

2-Amino-3-methylaminoquinol Diethyl Ether.—2 : 3-Diaminoquinol diethyl ether (58 g.), methyl iodide (50 ml.), and methanol (750 ml.) were refluxed for 2 days. Colourless crystals were obtained on cooling the concentrated mixture. These were dissolved in water, basified with sodium hydroxide, and extracted with ether. After removal of the dried ethereal extract the residue was distilled under reduced pressure, and the above *base* obtained, b. p. 124°/0·5 mm., m. p. 47—48° (Found : C, 63·0; H, 8·65; N, 13·2. $C_{11}H_{16}O_2N_2$ requires C, 62·9; H, 8·6; N, 13·3%). The *dihydrochloride* had m. p. 122° (from ethanol) (Found : N, 8·6; Cl, 21·7. $C_{11}H_{20}O_2N_2Cl_2,C_2H_5{\cdot}OH$ requires N, 8·5; Cl, 21·6%), and the *hydriodide* m. p. 163—165° (decomp.) (Found : C, 39·4; H, 5·5; N, 8·2; I, 57·4. $C_{11}H_{19}O_2N_2I$ requires C, 39·0; H, 5·6; N, 8·3; I, 37·5%).

TABLE 1. *Benziminazole perchlorates.*

Substituents in position : 1	2	4	M. p.*	Formula	Found (%) N	Found (%) Cl	Reqd. (%) N	Reqd. (%) Cl
H	H	OMe	195—200°	$C_8H_9O_5N_2Cl$	11·2	14·3	11·3	14·3
H	Me	OMe	255—256	$C_9H_{11}O_5N_2Cl$	11·3	13·0	10·7	13·5
H	Et	OMe	217—218	$C_{10}H_{13}O_5N_2Cl$	9·7	13·05	10·1	12·85
H	Pr^i	OMe	153—155	$C_{11}H_{15}O_5N_2Cl$	9·8	13·15	9·65	12·2
H	Bu^t	OMe	232—233	$C_{12}H_{17}O_5N_2Cl$	9·1	11·95	9·2	11·7
H	H	OH	203—204	$C_7H_7O_5N_2Cl$	11·8	15·7	11·95	15·15
H	Me	OH	177—178	$C_8H_9O_5N_2Cl$	11·3	14·7	11·3	14·3
H	Pr^i	OH	80—85	$C_{10}H_{13}O_5N_2Cl$	—	13·6	—	12·8
H	Bu^t	OH	227—230	$C_{11}H_{15}O_5N_2Cl$	9·7	11·35	9·6	12·2

* All with decomposition.

TABLE 2. *Miscellaneous substituted benziminazole hydrohalides.*

Substituent in position : 1	2	4	7	M. p.	Formula	Found (%) N	Found (%) Cl (or Br)	Reqd. (%) N	Reqd. (%) Cl (or Br)
H	H	OH	H [a]	282—283°	$C_7H_7ON_2Cl$	15·9	20·2	16·4	20·8
H	Et	OH	H	212—214	$C_9H_{11}ON_2Cl$	14·3	18·1	14·1	17·9
H	Pr^i	OH	H	215·5	$C_{10}H_{13}ON_2Cl$	13·3	16·2	13·2	16·7
H	Bu^t	OH	H	241·5	$C_{11}H_{15}ON_2Cl$	11·9	15·1	12·3	15·7
Me	H	OH	OH	256—259	$C_8H_9O_2N_2Cl,H_2O$	12·5	15·9	12·8	16·2
H	C_3F_7	OH	H [b]	97—99	$C_{10}H_4ON_2F_7Br,H_2O$	6·9	19·5	7·0	19·9
Me	CF_3	OH	OH [c]	224·5	$C_9H_6O_2N_2F_3Br$	9·25	—	8·95	—

[a] Sorkin, Roth, and Erlenmeyer [1] give m. p. 275—278°. [b] Found : C, 29·4; H, 2·4. Reqd. : C, 29·9; H, 2·0%. [c] Found : C, 35·3; H, 3·7. Reqd. : C, 34·5; H, 2·6%.

Note added in Proof.—Similar details for the preparation of some of these compounds are given in U.S.P. 2,663,712 (General Aniline and Film Corp.) but without m. p.s or analytical data.

Preparation of 2-Substituted Benziminazoles.—Equimolecular mixtures of the *o*-diamines (2 : 3-diaminoanisole, 2 : 3-diaminoquinol diethyl ether, and 2-amino-3-methylaminoquinol diethyl ether) and the appropriate acid were refluxed for 12 hr. in aqueous 4N-hydrochloric acid. The mixture was filtered and neutralised with sodium hydrogen carbonate, and the precipitated bases filtered off, washed, dried, purified by vacuum distillation, and crystallised from aqueous ethanol. When perfluoro-acids were used the vacuum distillation was omitted. Results are given in Tables 2, 3, and 5.

TABLE 3. *4-Methoxy-2-substituted benziminazoles.*

Substituent in position 2	M. p.	Equiv. Found	Equiv. Reqd.	Method	Formula	Found (%) C	Found (%) H	Found (%) N	Reqd. (%) C	Reqd. (%) H	Reqd. (%) N
H	169—170°	147	148	(*a*) (i)	$C_8H_8ON_2$	64·7	5·3	18·8	64·9	5·45	18·9
Me	193	162	162	,,	$C_9H_{10}ON_2$	66·7	6·2	17·0	66·6	6·2	17·3
Et	136—139	177	176	,,	$C_{10}H_{12}ON_2$	68·1	6·9	15·9	68·1	6·9	15·9
Pr^i	203·5	189	190	,,	$C_{11}H_{14}ON_2$	69·1	7·3	14·8	69·4	7·4	14·8
Bu^t	233·5	204	205	,,	$C_{12}H_{16}ON_2$	70·4	8·0	15·2	80·6	7·9	13·7
CF_3	169—172	220	216	(*b*)	$C_9H_7ON_2F_3$	50·6	2·8	13·2	50·0	3·3	13·0
C_2F_7	189—190	320	316	(*b*)	$C_{11}H_7ON_2F_7$	41·8	2·2	9·15	41·8	2·2	8·9

TABLE 4. *4-Hydroxy-2-substituted benziminazoles.*

Substituent in position 2	M. p.	Equiv. Found	Equiv. Reqd.	Method	Formula	Found (%) C	Found (%) H	Found (%) N	Reqd. (%) C	Reqd. (%) H	Reqd. (%) N
H [a]	200° (decomp.)	134	134	(*a*) (i)	$C_7H_6ON_2$	62·8	4·4	20·8	62·7	4·5	20·9
Me	216·5	149	148	(*b*)	$C_8H_8ON_2$	—	5·3	18·7	—	5·4	18·9
Et	157—159	163	162	(*a*) (ii)	$C_9H_{10}ON_2$	—	6·15	17·8	—	6·2	17·3
Pr^i [b]	191—193	88	88	(*b*)	$C_{10}H_{12}ON_2$	67·9	6·8	15·7	68·2	6·8	15·9
Bu^t	273·5	190	190	(*a*) (i)	$C_{11}H_{14}ON_2$	69·7	7·5	14·7	69·5	7·4	14·7
CF_3 [c]	173—174	207 104	202 101	(*b*)	$C_8H_5ON_2F_3,H_2O$	44·1	3·5	12·5	43·6	3·2	12·7

[a] Sorkin, Roth, and Erlenmeyer [1] give m. p. 151—152°. [b] Titration in dimethylformamide. [c] Titration in dimethylformamide; two inflexion points are obtained, due to the separate neutralisation of the phenolic OH group and the 1-H atom.

TABLE 5. *1-Methyl-2 : 4 : 7-trisubstituted benziminazoles.*

Substituent in position: 2	4	7	M. p.	Formula	Found (%) C	Found (%) H	Found (%) N	Reqd. (%) C	Reqd. (%) H	Reqd. (%) N
CF_3	OEt	OEt	111—113°	$C_{13}H_{13}O_2N_2F_3$	54·1	5·2	9·55	54·1	5·25	9·7
CF_3	OH	OH	241—242	$C_9H_7O_2N_2F_3$	46·7	3·3	11·9	46·5	3·0	12·0
CF_3	OAc	OAc	128—129	$C_{13}H_{11}O_4N_2F_3$	49·3	3·8	9·6	49·3	3·5	8·9
H	OEt	OEt [a]	107—108	$C_{12}H_{16}O_2N_2$	65·2	6·8	12·9	65·45	7·3	12·7
H	AcO	OAc	218—129	$C_{13}H_{12}O_4N_2,\frac{1}{2}H_2O$	56·0	5·1	10·9	56·3	5·3	11·0
Me	OEt	OEt	98—99	$C_{13}H_{18}O_2N_2$	67·1	7·7	11·7	66·7	7·7	12·0

[a] Found: equiv. (*a*, i), 222. Reqd.: equiv., 220. [b] Found: equiv. (*a*, i), 233. Reqd.: equiv., 234.

Dealkylation.—The appropriate benziminazole was refluxed in benzene for 6 hr. with 2·1 mol. of anhydrous aluminium chloride. The benzene was then distilled off, the residual solid triturated with water, and the hydroxybenziminazole, isolated as its hydrochloride by addition of concentrated hydrochloric acid, was purified by repeated treatment of the aqueous solutions of the hydrochloride with charcoal, followed by addition of concentrated hydrochloric acid until the salt crystallised. Free bases were prepared by addition of a slight excess of sodium hydrogen carbonate solution to an aqueous solution of the corresponding hydrochloride, followed by repeated crystallisation (aqueous ethanol) of the precipitated base.

When the 2-substituent was a perfluoroalkyl group, dealkylation was effected by 6 hours' refluxing with concentrated hydrobromic acid. The hydrobromide which crystallised on cooling was hydrolysed by addition of water, and the free base recovered and crystallised (ethanol). Results are given in Tables 2, 4, and 5.

Reaction of 4-Hydroxy- and 4 : 7-Dihydroxy-benziminazole with Pyridine and Acetic Anhydride.—4 : 7-Dihydroxybenziminazoles were characterised by acetylation of the corresponding hydroxy-compound with pyridine and acetic anhydride; in the 4-hydroxybenziminazole series the only compounds giving the expected products were those containing a 2-perfluoroalkyl group.

4-Acetoxy-2-trifluoromethylbenziminazole, m. p. 130° (decomp.) (Found: C, 49·4; H, 2·9; N, 11·3. $C_{10}H_7O_2N_2F_3$ requires C, 49·2; H, 2·9; N, 11·5%), and *4-acetoxy-2-heptafluoropropylbenziminazole*, m. p. 160° (Found: C, 41·1; H, 2·7; N, 8·3. $C_{12}H_7O_2N_2F_7$ requires C, 41·9; H, 2·0; N, 8·1%), were obtained by this route. 4-Hydroxybenziminazole similarly treated gave *4(7)-acetoxy-1-acetylbenziminazole*, m. p. 106° (Found: C, 60·6; H, 4·4; N, 13·4. $C_{11}H_{10}O_2N_2$ requires C, 60·5; H, 4·6; N, 12·9%). With higher homologues in the 2-position products of unknown constitution were obtained which evolved acetic acid on drying and storage.

4-Methoxybenzotriazole.—2 : 3-Diaminoanisole (27·6 g.) was dissolved in glacial acetic acid (24 g.) and water (60 ml.) at 5°, and a cold solution of sodium nitrite (15 g.) in water (25 ml.) added in one portion. The temperature rose to 80° and after 1 hr. the dark red-brown, oily layer formed was removed, dried, and distilled under reduced pressure. The *base* was obtained as a yellow solid, b. p. 206—208°/0·5 mm. (19·5 g.), and after several recrystallisations (benzene) had m. p. 133·5—135° [Found: N, 28·2%; equiv. (*b*), 146. $C_7H_7ON_3$ requires N, 28·2%; equiv., 149].

4-Hydroxybenzotriazole.—4-Methoxybenzotriazole (5·9 g.) was refluxed for 8 hr. with anhydrous aluminium chloride (10 g.) in benzene (1 l.), water (200 ml.) was added, with stirring, and the aqueous layer evaporated to dryness, leaving a yellow solid. After recrystallisation

(water) the *hydroxy-base* had m. p. 215·5—217·5° [Found : N, 31·0%; equiv. (*b*), 69. $C_6H_3ON_3$ requires N, 31·1%; equiv., 67·5]. With acetic anhydride and pyridine *4-acetoxybenzotriazole* was obtained, m. p. 170—171° [Found : N, 23·8%; equiv. (*b*), 90. $C_8H_7O_2N_3$ requires N, 23·8%; equiv., 88·5].

4-Hydroxybenzoxazole.—2-Aminoresorcinol hydrochloride (4 g.) and formamide (1·2 g.) were refluxed for 15 min. The mixture was extracted with ethanol, and colourless crystals were obtained on concentration of the extract. These were purified by dissolving them in aqueous sodium hydroxide followed by neutralisation with dilute hydrochloric acid. After crystallisation (ethanol) the base melted at 185° (Found : N, 10·0. Calc. for $C_7H_5O_2N$: N, 10·4%). Sorkin, Roth, and Erlenmeyer [1] record m. p. 180—181°. *4-Hydroxy-2-methylbenzoxazole*, obtained similarly from acetamide and 2-aminoresorcinol hydrochloride, had m. p. 143° [Found : C, 64·4; H, 4·8; N, 9·75%; equiv.(*b*), 148. $C_8H_7O_2N$ requires C, 64·4; H, 4·7; N, 9·4%; equiv., 149].

4-Hydroxybenzo-2 : 1 : 3-selenadiazole.—4-Methoxybenzo-2 : 1 : 3-selenadiazole [7] (21 g.) was refluxed in benzene (150 ml.) with anhydrous aluminium chloride (28 g.) for 6 hr. Water was added, and the mixture boiled for a further 15 min. The benzene layer was concentrated, and the solid which separated filtered off. After several recrystallisations (ethylene glycol or diethyl oxalate) the above *hydroxy-base* formed red-brown plates, m. p. 187—188° [Found : C, 36·0; H, 2·0; N, 14·4%; equiv.(*b*), 204. $C_6H_4ON_2Se$ requires C, 36·2; H, 2·0; N, 14·1%; equiv., 209]. The corresponding *acetoxy-compound*, prepared by use of pyridine and acetic anhydride, formed felted yellow needles, m. p. 66—60° (decomp.) (Found : C, 39·7; H, 2·6; N, 12·1. $C_8H_6O_2N_2Se$ requires C, 39·8; H, 2·5; N, 11·6%).

Dealkylation of 4 : 7-Diethoxybenzo-2 : 1 : 3-selenadiazole.—This base [8] was recovered unchanged after 6 hours' refluxing in benzene with 1 mol. of anhydrous aluminium chloride. With 2 mols., *4-ethoxy-7-hydroxybenzo-2 : 1 : 3-selenadiazole* was obtained by the above procedure as scarlet needles from ethanol, m. p. 187—187·5° [Found : C, 39·2; H, 3·4; N, 11·8%; equiv. (*b*), 238. $C_8H_8O_2N_2Se$ requires C, 39·5; H, 3·3; N, 11·5%; equiv., 243]. The corresponding *acetoxy-compound* (pyridine and acetic anhydride) formed yellow needles, m. p. 154·5—155° (with sublimation; from ethanol) (Found : C, 42·3; H, 3·3; N, 9·5. $C_{10}H_{10}O_3N_2Se$ requires C, 42·1; H, 3·5; N, 9·8%). With 3 mols. of aluminium chloride further dealkylation occurred but the product was oxidised rapidly on attempted isolation.

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[7] Lane and Williams, *J.*, 1954, 2971.
[8] *Idem*, *J.*, 1955, 1469.

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116. *Structural and Stereochemical Investigations of Cyclic Bases. Part I. 3-(Tertiary Amino)-steroids.*

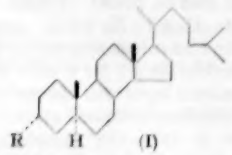
By B. B. GENT and J. MCKENNA.

A kinetic investigation of the Menschutkin reaction of methyl iodide with a series of 3-(tertiary amino)-steroids in nitrobenzene–benzene has shown that the equatorial bases examined have lower energies of activation and lower " frequency factors " than their axial epimers. Hofmann, Emde, and amine oxide degradations of some of the steroidal bases are also described.

EQUATORIAL hydroxyl (or carboxyl) groups are more readily esterified than the epimeric, axial groups, and a similar differentiation has been observed for other reactions, including ester hydrolysis (for discussions and leading earlier references see Barton [1] and Klyne [2]). These conclusions are based for the most part on qualitative observations or quantitative data of the simplest type, as few relevant kinetic investigations have been made. If we consider a group R–X–Y in which R is a *cyclo*hexane or reduced six-membered heterocyclic residue and –XY an equatorial or axial substituent, then addition or bimolecular substitution reactions *at* X (the atom directly attached to the nucleus) would, in general, be expected to proceed more readily for X (equatorial) than for X (epimeric and axial).

[1] Barton, *J.*, 1953, 1027.
[2] Klyne (Ed.), " Progress in Stereochemistry," Butterworths, London, 1954.

In each of these reaction types an additional atom or group becomes partially bonded to X in the transition state, and the prediction regarding differential reactivity is readily and directly based on the normal * fundamental greater accessibility, and lower steric compression of (in our example) equatorial rather than axial X. Alkaline hydrolysis of epimeric steroidal acetates and benzoates is probably classifiable, in relation to the group R–X–Y, as bimolecular substitution at Y, but, in general, predictions regarding differential reactivity are less readily made for this and other types of substitution reaction involving X–Y. Among other such reactions is displacement of a substituent at a *cyclo*hexane carbon atom (for a relevant discussion see Fieser [4]).



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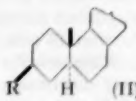

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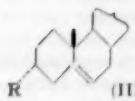

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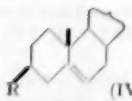

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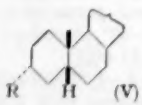

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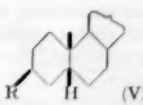

(VI)

To provide some detailed information on an addition reaction of the type referred to above, we have made a kinetic study of the Menschutkin reaction, with methyl iodide, of the epimeric 3-dimethylamino-cholestanes (I and II; R = NMe_2), -cholest-5-enes (III and IV; R = NMe_2), and -coprostanes (V and VI; R = NMe_2). A conductometric procedure was used, concentrations of quaternary iodide being determined by reference to empirical conductance–concentration curves, and only *ca.* 5 mg. of amine were required for each run. In a preliminary check of the apparatus a value $k = 5{\cdot}57 \times 10^{-5}$ l. mole^{-1} sec.$^{-1}$ was observed for the second-order rate constant of the reaction of dimethylaniline and methyl iodide in methanol at 24·9°; using a different procedure Evans [5] recorded $k = 5{\cdot}62 \times 10^{-5}$ l. mole^{-1} sec.$^{-1}$ at 25°. Preliminary results with the alicyclic bases in methanol suggested that an aprotic solvent was required at the low concentrations employed, and we therefore used nitrobenzene to which 10% w/w of benzene was added to permit runs at 0°. All six steroidal quaternary iodides gave the same calibration curve (conductance–concentration) at 24·9°; at other temperatures, therefore, the conductances for a random selection from the six salts were taken as applicable to all the others.

Good second-order rate constants were obtained for all the bases at 0·0°, 12·0°, and 24·9°; results for a typical run are shown in Table 1, together with the rate constants and values for E and log A derived by graphical analysis of the results using the Arrhenius equation $k = A \exp(-E/\boldsymbol{R}T)$. The Arrhenius plots are excellent in some cases and satisfactory in all. Additional analysis on the basis of the absolute-rate expression is unnecessary for the purposes of our discussion.

Equatorial amines (II; IV; V; R = NMe_2) have lower energies of activation (heats of activation follow the same order) than have the axial bases (I; III; VI; R = NMe_2) and the results thus illustrate the soundness of one aspect of conformational theory. The Arrhenius "frequency factors" (which provide an indication of relative entropies of activation) for the equatorial bases are also lower than for their epimers; the difference is probably mainly due to the greater degree of solvation possible with intermediate complexes derived from the less hindered amines.[6]

* For a discussion of special cases where an equatorial group is more hindered than an epimeric axial group, see Klyne.[3]

[3] Klyne (Ed.), *op. cit.*, p. 53.
[4] Fieser, *Experientia*, 1950, **6**, 312.
[5] Evans, *J.*, 1944, 422.
[6] *Cf.* Evans and Hamann, *Trans. Faraday Soc.*, 1951, **47**, 25.

The kinetic runs were normally followed to about half completion, and no difficulties due to the reversibility of the reaction were encountered: results in all cases fitted the simple second-order rate expression. Equilibration experiments, however, showed that the Menschutkin interchange reaction, $R{\cdot}NMe_3\}I + R'{\cdot}NMe_2 \rightleftharpoons R{\cdot}NMe_2 + R'{\cdot}NMe_3\}I$, may be important at higher temperatures. An approximately equimolecular mixture of

TABLE 1. *Typical kinetic run, rate constants, and Arrhenius parameters for steroidal amines in the Menschutkin reaction.*

3β-Dimethylaminocoprostane at 0°; $[MeI]_0$ = 180·1 mM; $[Base]_0$ = 6·87 mM.

Time (min.)	50	70	90	110	130	150
Conductance (μmho)	90	116	139	159	178	194
[Quaternary iodide] (mM)	1·26	1·70	2·08	2·44	2·79	3·10
10^3k (l. mole^{-1} sec.$^{-1}$)	0·376	0·378	0·373	0·372	0·374	0·374

Average k = 0·375 × 10^{-3}; corr. for time, 0·378 × 10^{-3} l. mole^{-1} sec.$^{-1}$.

Base no.	I	II	III	IV	V	VI
$10^3k_{24\cdot9}$ (l. mole^{-1} sec.$^{-1}$)	1·14	81·5	6·41	54·6	89·2	2·51
$10^3k_{12\cdot0}$,,	0·42	44·0	2·51	28·0	43·9	0·96
$10^3k_{0\cdot0}$,,	0·16	24·1	0·98	13·2	23·8	0·38
E (kcal. mole^{-1})	12·7	7·9	12·2	9·3	8·7	12·4
log A	6·4	4·7	6·8	5·6	5·3	6·4

3β-dimethylaminocoprostane methiodide (VI; R = $NMe_3\}I$) and 3α-dimethylaminocoprostane (V; R = NMe_2) was heated in benzene–nitrobenzene at 200°; in our preliminary experiments the reaction mixture has not been fully analysed, but it was evident that the chief basic component was 3β-dimethylaminocoprostane (VI; R = NMe_2), the larger trimethylammonium group favouring the equatorial (3α) site. This type of equilibration may be of general interest in comparisons of steric compressions at different positions in reduced cyclic systems.

Previous work has shown that certain axial steroidal 3-trimethylammonium groups are readily eliminated by Hofmann fission, but that saturated equatorial quaternary hydroxides preferentially lose methanol on pyrolysis.[7] We have found that the same is true for the epimeric 3α(equatorial)- and the 3β(axial)-coprostanyltrimethylammonium hydroxide (V and VI; R = $NMe_3\}OH$); preliminary evidence regarding pyrolysis of the former was included in the earlier paper, but the structure of the related tertiary amine was not elucidated until later.[8] It is not at present known to what extent differences in the relative rates of the methanol-elimination reactions affect the composition of the reaction mixture in these pyrolyses.

We have examined some Emde reductions of steroidal 3-quaternary ammonium chlorides and iodides; the most interesting result concerns the epimeric cholest-5-enyl 3-quaternary salts. The tendency towards Hofmann elimination in the 3α-cholest-5-enyltrimethylammonium ion (III; R = NMe_3^+) is so strong (axial nitrogen; formation of conjugated diene system) that treatment of the chloride in water with sodium amalgam or of the iodide with sodium in liquid ammonia yields cholesta-3 : 5-diene; the normal Emde product, cholest-5-ene, has not been isolated from these reactions, but may be obtained in low yield by sodium amalgam reduction of 3β-cholest-5-enyltrimethylammonium chloride (IV; R = $NMe_3\}Cl$). Use of ethanol in alkali-metal–liquid ammonia reductions has been recommended by Birch[9] for countering reactions due to the strongly basic amide anion, and we found that 3α-cholest-5-enyltrimethylammonium iodide with sodium in ethanol–liquid ammonia gave cholest-5-ene. On Emde reduction (sodium amalgam) of four saturated quaternary chlorides (I, II, V, VI; R = $NMe_3\}Cl$), significant unsaturation could not be detected in the hydrocarbon fractions even from the two axial salts.

Pyrolysis of tertiary amine oxides affords, *inter alia*, the related tertiary amines and

[7] Haworth, McKenna, and Powell, *J.*, 1953, 1110.
[8] (*a*) Šorm, Lábler, and Černý, *Chem. Listy*, 1953, **47**, 418; 1954, **48**, 1058; (*b*) Haworth, Lunts, and McKenna, *J.*, 1955, 986.
[9] Birch, *Quart. Rev.*, 1950, **4**, 69.

olefins, and it has been suggested that the nitrogen-elimination reaction assumes a *cis*-steric course.[10] Thus, oxides derived from axial and equatorial amines would be expected to give comparable yields of olefin on pyrolysis, and we have demonstrated this for the four amines listed in Table 2; yields of crude olefin and tertiary amine obtained on Hofmann degradation are included for comparison (Hofmann yields for the epimeric 3-dimethylaminocholestanes are calculated from the data of Haworth, McKenna, and Powell [7]).

TABLE 2. *Yields of hydrocarbon and recovered tertiary base on Hofmann degradation or amine oxide pyrolysis of steroid bases.*

Base no.	Crude hydrocarbon (%)		Crude recovered base (%)	
	Hofmann	Amine oxide	Hofmann	Amine oxide
(I) R (axial) = NMe_2	79	87	17	6
(VI) R (axial) = NMe_2	66	58	17	16
(II) R (equatorial) = NMe_2	4	63	92	33
(V) R (equatorial) = NMe_2	18	58	63	17

In the preparation of the amine oxides it was observed qualitatively that equatorial bases reacted faster than the axial epimers. The pyrolysis mixtures were much cleaner and more readily purified than those from Hofmann degradations.

EXPERIMENTAL

Kinetic Investigation.—(a) *Preparation and purification of materials.* 3α-, m. p. 90—91° (methiodide, m. p. 285—286°), and 3β-Dimethylaminocholestane, m. p. 102—104° (methiodide, m. p. 285—286°), 3α-, m. p. 70—71·5° (methiodide, m. p. 289—290°), and 3β-dimethylaminocholest-5-ene, m. p. 149—150° (methiodide, m. p. 303—305°), 3α-, m. p. 72—74° (methiodide, m. p. 264—265°), and 3β-dimethylaminocoprostane, m. p. 62° [*methiodide*, m. p. 291—293° (Found: C, 64·2; H, 9·9; N, 2·2; I, 22·9. $C_{30}H_{56}NI$ requires C, 64·6; H, 10·1; N, 2·5; I, 22·8%)], and trimethylphenylammonium iodide, m. p. 216—217°, were prepared by described methods (for the steroid preparations see Haworth *et al.*[7] and Sorm *et al.*[8a]), recrystallised (bases from acetone; quaternary iodides from methanol) to constant m. p., and dried *in vacuo*. The m. p.s of the quaternary iodides vary considerably according to conditions of heating: those quoted are for immersion *ca.* 20° below the m. p. in an electrically heated block the temperature of which was then raised by approx. 10° per min.

Methanol was treated with magnesium and iodine [11] and distilled. Nitrobenzene was washed with water, dried ($CaCl_2$), and distilled. Benzene ("AnalaR") was fractionally distilled, the first 10% being rejected. Methyl iodide was twice distilled from potassium carbonate, and stored in a dark bottle over mercury. Dimethylaniline ("AnalaR") was distilled from potassium hydroxide. Fractions of steady b. p. in agreement with values in the literature were accepted from these distillations, in which a Widmer column was used where necessary.

A mixture of 1 part by weight of benzene and 9 parts of nitrobenzene had d 1·154 at 25°, and 1·173 at 0°; by intrapolation d at 12° was 1·164.

(b) *Apparatus and method.* The conductivity cell was a two-limbed Pyrex vessel of 6 c.c. volume, shaped like a Zerewitinoff tube, with bright platinum electrodes (20 × 5 × 0·5 mm.) firmly located about 4 mm. apart in one limb by glass spacers. In use the cell was closed with a rubber bung through which passed a glass rod terminating in a Polythene plug which fitted the outlet from the second limb. The glass rod also supported a Polythene washer against the lower face of the rubber bung. In each kinetic run the amine solution was placed in the electrode limb, and the methyl iodide solution (total vol. of both solutions about 3 c.c.) in the other which was then closed with the Polythene plug. The cell was kept for 15—30 min. in a bath the temperature of which (measured with a standardised thermometer) was held constant within 0·01°. The Polythene plug was then withdrawn without disturbing the rubber bung or its Polythene washer, the cell contents were mixed, and readings were started; resistances (usually 2500—100,000 ohms) were measured on a conventional Wheatstone-bridge circuit with earphone detector and compensating condenser, using A.C. at 5 v and 1250 c.p.s. supplied from an oscillator kept about 6 ft. from the rest of the apparatus. Conductances (10—400 μmho) were

[10] Cope, Pike, and Spencer, *J. Amer. Chem. Soc.*, 1953, **75**, 3212 and earlier papers; Cram and McCarty, *ibid.*, 1954, **76**, 5740 and earlier papers; Rogers, *J.*, 1955, 769.

[11] Lund and Bjerrum, *Ber.*, 1931, **64**, 210.

also checked approximately during a run with a Mullard conductivity bridge. Molar concentrations were corrected for temperature, and it was found that concentrations of amine or methyl iodide of the same order as those required for the kinetic work had no appreciable effect on the conductances of quaternary iodide solutions.

Variations in rate constants were less than 1·5% from the arithmetical means quoted, which are for ranges of 15—40% reaction; it was usually necessary to reject the first few readings.

Equilibration Experiments.—3β-Coprostanyltrimethylammonium iodide (95 mg.) and 3α-dimethylaminocoprostane (61 mg.) in benzene–nitrobenzene (as used in kinetic work; 10 c.c.) were heated in a sealed Pyrex tube at 200° for 1 hr., the solvent was evaporated, and the basic fraction (50 mg.) was crystallised twice from acetone, yielding 3β-dimethylaminocoprostane as prisms, m. p. 59—60°, undepressed on admixture with an authentic specimen of m. p. 62°. For further characterisation the base was converted into the *picrate*, m. p. 202—203° (from methanol) undepressed on admixture with an authentic specimen prepared as described below.

When 3α-coprostanyltrimethylammonium iodide (35 mg.) and 3β-dimethylaminocoprostane (27 mg.) were heated in benzene–nitrobenzene (5 c.c.) at 200° for 1 hr., recovered 3β-dimethylaminocoprostane, m. p. 60—61°, was the main component of the basic fraction.

Emde Reduction of 3α-Dimethylaminocholest-5-ene Metho-salts.—(a) *With sodium amalgam.* The amine (111 mg.) was converted into the quaternary iodide and thence into the quaternary chloride in the usual way. The chloride in water (30 c.c.) was treated at 100° with 5% sodium amalgam (5 g.) during 6 hr., and the mixture was separated into neutral (72 mg.) and basic (15 mg.) components. The latter was distilled *in vacuo* and the distillate crystallised from acetone, yielding crude 3α-dimethylaminocholest-5-ene, m. p. 66—67°, undepressed on admixture with an authentic specimen of m. p. 70—71°. The neutral component after chromatography on alumina and recrystallisation from methanol–ether gave cholesta-3 : 5-diene, m. p. and mixed m. p. 75—76°, together with fractions of lower m. p. (*ca.* 55°) which exhibited a strong band at 2350 Å (in EtOH; log ε 4·10). No cholest-5-ene could be isolated.

(b) *With sodium in liquid ammonia.* A suspension of methiodide (500 mg.) from 3α-dimethylaminocholest-5-ene in liquid ammonia (300 c.c.) was treated during 30 min. with sodium until a slight excess was present, and the solvent was then allowed to evaporate. After one recrystallisation from methanol–ether the neutral product (200 mg.) had m. p. 75—76° undepressed on admixture with cholesta-3 : 5-diene.

(c) *With sodium in ethanol–liquid ammonia.* Methiodide (239 mg.), suspended in liquid ammonia (50 c.c.) and ethanol (5 c.c.), was treated portionwise with a slight excess of sodium, and the mixture was separated into basic and neutral fractions. The basic fraction (40 mg.), on crystallisation from acetone, yielded 3α-dimethylaminocholest-5-ene, m. p. and mixed m. p. 69—70°. Two recrystallisations of the neutral fraction (65 mg.) from methanol–ether gave cholest-5-ene, m. p. and mixed m. p. 89—90°.

Emde Reduction of 3β-Dimethylaminocholest-5-ene Methochloride.—Base (97 mg.) was converted into the methochloride and reduced with sodium amalgam by the method outlined above. The ether-soluble products were 3β-dimethylaminocholest-5-ene (6 mg.), m. p. (from acetone–chloroform) 149—150°, undepressed on admixture with an authentic specimen, and a neutral fraction (3·3 mg.) which after distillation *in vacuo*, chromatography on alumina, and recrystallisation from methanol–ether gave cholest-5-ene, m. p. 84—85°, undepressed on admixture with an authentic specimen of m. p. 88—89°; a yellow oil, which failed to exhibit the characteristic absorption band of cholesta-3 : 5-diene at 2350 Å, was obtained from the final eluates of the chromatogram.

Emde Reduction of Saturated Quaternary Chlorides.—3α-Dimethylaminocholestane (65 mg.) on conversion into the methochloride and reduction with sodium amalgam gave recovered base (11 mg.) m. p. and mixed m. p. 88—89° after crystallisation from acetone, and an oily neutral fraction (12 mg.) which exhibited no appreciable unsaturation in a test with ethereal monoperphthalic acid at 0°. A solution of the oil in light petroleum (b. p. 40—60°) was chromatographed on alumina, and the product crystallised from methanol–ether, giving leaflets, m. p. 75°, undepressed on admixture with cholestane, m. p. 78—79°. 3β-Dimethylaminocholestane methochloride gave similar yields of recovered amine, m. p. 101—102°, and a saturated neutral oil from which, however, only partly crystalline material could be obtained on attempted purification.

3α-Dimethylaminocoprostane methochloride gave a similar result, only recovered amine, m. p. 69—70°, being characterised. 3β-Dimethylaminocoprostane methochloride (from methiodide; 69 mg.) gave recovered amine (8 mg.), m. p. 58—59° undepressed on admixture with 3β-dimethylaminocoprostane of m. p. 60—62°, and a saturated neutral fraction (8 mg.)

which on chromatography on alumina and crystallisation from methanol–ether yielded colourless needles of coprostane, m. p. and mixed m. p. 70—71°.

Hofmann Degradation of 3α- *and* 3β-*Dimethylaminocoprostanes.*—3α-Dimethylaminocoprostane methiodide (49 mg.) was converted in the usual way into the quaternary hydroxide which was pyrolysed at 160—180° (bath)/0·01 mm., yielding recovered amine (23 mg.), m. p. (from acetone) 68—69° undepressed on admixture with an authentic specimen of m. p. 72—74°, and an oily hydrocarbon (6 mg.). Hydrogenation of the hydrocarbon in ether–acetic acid in presence of platinum, and crystallisation of the product from ether–methanol, gave coprostane, m. p. and mixed m. p. 67—68°.

Similar treatment of 3β-dimethylaminocoprostane methiodide (112 mg.) afforded recovered amine (14 mg.), m. p. (from acetone) 60—61°, together with a neutral oil (49 mg.) which on hydrogenation yielded coprostane, m. p. and mixed m. p. 70—71° after crystallisation from methanol–ether.

Preparation and Characterisation of Amine Oxides.—The saturated tertiary amine, in methanol or methanol–chloroform, was treated at 70° for 24 hr. (equatorial bases) or 48 hr. (axial bases) with 30% hydrogen peroxide (2 mol.); excess of hydrogen peroxide was then decomposed by addition of a little platinum black.[12] When (in a few hours) the mixture failed to bleach lead sulphide paper the catalyst was separated by filtration and the filtrate evaporated. The white residue of amine oxide was triturated with boiling ether, and for characterisation was converted into picrate which was recrystallised from ethanol–chloroform. For comparison the tertiary amine picrates were prepared and recrystallised from ethanol or ethanol–chloroform. Data are as follows: 3α-, irregular yellow prisms, m. p. 198—200° (Found: C, 65·2; H, 8·9; N, 8·2. $C_{35}H_{54}O_7N_4$ requires C, 65·2; H, 8·8; N, 8·7%), and 3β-*dimethylaminocholestane picrate*, yellow prismatic needles, m. p. 260° (decomp.) (Found: C, 65·1; H, 8·7; N, 8·5%); 3α-, prisms, m. p. 199—201° (Found: C, 65·0; H, 9·0; N, 8·4%), and 3β-*dimethylaminocoprostane picrate*, prismatic needles, m. p. 202—203° (decomp.) (Found: C, 65·1; H, 8·8; N, 8·4%); 3α-, prisms, m. p. 166—168° (decomp.) (Found: C, 63·4; H, 8·8. $C_{35}H_{56}O_8N_4$ requires C, 63·6; H, 8·5%), and 3β-*dimethylaminocholestane oxide picrate*, plates, m. p. 200° (decomp.) (Found: C, 63·7; H, 8·8%); 3α-, prisms, m. p. 158—159° (Found: C, 63·3; H, 8·4%), and 3β-*dimethylaminocoprostane oxide picrate*, prisms, m. p. 155—157° (Found: C, 63·5; H, 8·8%).

Pyrolysis of Amine Oxides.—3α-Dimethylaminocholestane oxide (I; R = NMe_2O) (24 mg.) was heated for 15 min. at 170° (bath)/0·03 mm. and the distillate separated into basic (1·3 mg.) and neutral (18 mg.) fractions; the former was not examined. Hydrogenation of the neutral fraction in ether–acetic acid in presence of platinum oxide and crystallisation of the product from methanol–ether gave cholestane, m. p. and mixed m. p. 76—77°.

3β-Dimethylaminocholestane oxide (II; R = NMe_2O) (22 mg.) on pyrolysis at 170° (bath)/0·01 mm. similarly gave basic (7 mg.) and neutral (12 mg.) products; the base on crystallisation from acetone had m. p. 101—102°, undepressed on admixture with 3β-dimethylaminocholestane of the same m. p. Hydrogenation of the neutral fraction yielded cholestane, m. p. and mixed m. p. 77—78° after crystallisation from methanol–ether.

3α-Dimethylaminocoprostane oxide (V; R = NMe_2O) (18 mg.), on pyrolysis, likewise yielded 3α-dimethylaminocoprostane (3 mg.), m. p. 69—70° after crystallisation from acetone, undepressed on admixture with an authentic specimen of m. p. 72—74°; hydrogenation of the neutral pyrolysis product (9 mg.) and crystallisation from methanol–ether yielded coprostane, m. p. and mixed m. p. 67—68°.

Pyrolysis of 3β-dimethylaminocoprostane oxide (VI; R = NMe_2O) (26 mg.) gave tertiary base (4 mg.), m. p. 60—62° after crystallisation from acetone, undepressed on admixture with 3β-dimethylaminocoprostane of m. p. 62°, and a neutral fraction (13 mg.) which afforded coprostane, m. p. and mixed m. p. 69—70°, after hydrogenation and crystallisation of the product from methanol–ether.

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The University, Sheffield. [*Received, July 11th*, 1955.]

[12] Feulgen, *Ber.*, 1921, **54**, 360.

117. *Alkyl Sulphates. Part I. Critical Micelle Concentrations of the Sodium Salts.*

By H. C. Evans.

The variation in specific conductivity with change in concentration of aqueous solutions has been used in determining the critical micelle concentrations of a number of sodium alkyl sulphates in which the total hydrocarbon chain contains 8—19 carbon atoms and the position of the sulphate group ranges from the terminal to the medial position. Data are also presented for sodium 1-tetradecylpentadecyl sulphate. The slopes of the plots are used in estimating the number of gegenions in the micelles.

Sodium alkyl sulphates, $CHRR'\cdot O\cdot SO_2\cdot ONa$, where R and R′ are unbranched, have very similar chemical properties. Except when the SO_4Na group occupies the ultimate or penultimate position, many of them are difficult or impossible to crystallize, and their identification by means of their chemical or the more usual physical properties is difficult. To assist in their identification the concentrations at which micelles first form in aqueous solution have been measured. This, it was thought, would suffice to identify isomers, and homologues could be distinguished by other methods.

Published information on the critical micelle concentrations of these compounds is scanty. Apart from the primary dodecyl sodium sulphate which has been used by many workers, almost the only alkyl sulphates which have been examined are the homologous 1-sulphates. These have been studied by Harkins and his co-workers [1] using the spectral (dye) method, by Lottermoser and Püschel [2] and by Flockhart and Ubbelohde [3] using a conductivity method, and by Powney and Addison [4] who measured the reduction in surface tension; these series of results are not in good agreement. Winsor [5] has reported the critical micelle concentrations of the isomeric sodium C_{14}-alkyl sulphates. Certain drawbacks and advantages are peculiar to each of the above methods of which the two most popular are the spectral (dye) method and the conductivity method. The former is technically simple, but the end point is not sharp and reliance must be placed on comparison with standard colours. Further, there are certain anomalies concerning the results obtained by this method which cast doubt on its theoretical significance.[6] In the present work the critical micelle concentrations have been determined by repeated measurement of conductivity as the solution is diluted. This method, in addition to giving a fairly precise value for this concentration, may also be interpreted so as to yield information on the actual mechanism of micelle formation.

Experimental

Materials.—Since many substances, *e.g.*, inorganic salts and long-chain alcohols, lower the critical micelle concentration of surface-active compounds, the compounds studied should be as pure as possible. Their preparation will be described in Part II of this series. Sodium *n*-alkyl and 1-methylalkyl sulphates were purified by recrystallization from ethyl methyl ketone and water. The other compounds (except one) were available only as solutions in water. In general these solutions contained $<1\%$ of impurity (see Part II), but they were further purified by foam-fractionation before use.

This was accomplished by blowing nitrogen through an approx. 1% solution of the alkyl sulphate contained at the base of a column 60 cm. in height. The rate of gas flow was adjusted so that the foam produced by the gas stream collapsed spontaneously at the top of the column; the resulting liquid was collected in the head of the apparatus and drained to a receiver.[7] This

[1] Corrin and Harkins, *J. Amer. Chem. Soc.*, 1947, **69**, 679; Harkins, *ibid.*, p. 1428; Corrin, Klevens, and Harkins, *J. Chem. Phys.*, 1946, **14**, 480.
[2] Lottermoser and Püschel, *Kolloid Z.*, 1933, **63**, 175.
[3] Flockhart and Ubbelohde, *J. Colloid. Sci.*, 1953, **8**, 428.
[4] Powney and Addison, *Trans. Faraday Soc.*, 1937, **33**, 1243.
[5] Winsor, *ibid.*, 1948, **44**, 463.
[6] Klevens, *J. Phys. Colloid Chem.* 1947, **51**, 1143; Mukerjee and Mysels, *J. Amer. Chem. Soc.*, 1955, **77**, 2937.
[7] Epton and Evans, Proc. 1st World Congr. on Surface Active Agents, in the press.

principle is not new [8] but it must be realized that (*a*) large quantities of unfractionated material are entrained unless the foam is allowed to drain thoroughly (this is achieved by allowing the foam to collapse spontaneously), and (*b*) inorganic salts are not removed in the foam, so that residual solution is richer therein than the original material. The procedure in the present experiments was to remove by foaming, and discard, the first third of the total surface-active material; this contained all the organic impurities. About half of the remainder was collected and used for conductivity measurements, while the inorganic salt remained behind.

The water used for dilution was treated as follows: Laboratory-distilled water was fractionally distilled in a glass apparatus and stored in closed bottles, freshly distilled water being used each day. Its specific conductivity varied between 5 and 1×10^{-6} ohm^{-1} cm.$^{-1}$.

Apparatus.—A conductivity bridge supplied with current at 1 kc. sec.$^{-1}$ from a Muirhead audio-frequency oscillator was used for part of this work. The balance point was detected by a headphone. This proved convenient for solutions the measured resistance of which did not rise above *ca.* 3000 ohms, but at higher resistances it became increasingly difficult to detect the

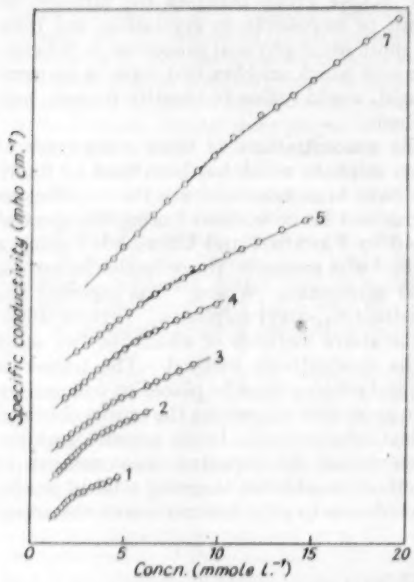

FIG. 1. *Specific conductivity of isomeric sodium C_{14}-alkyl sulphates.*
The conductivity ordinate has been shifted for each compound. The numerals for the individual curves denote the position (*P*) of the $NaO{\cdot}SO_3{\cdot}O$ in the chain $R{\cdot}CH{\cdot}R'$.

balance point owing to the low sound level and to capacity effects. In later work a bridge was used in which the balance point was detected by a Cambridge galvanometer. It also operated at 1 kc. sec.$^{-1}$ with an accuracy of 0·1 ohm at 1000 ohms, and the capacity of the cell assembly could be balanced out by means of variable condensers. The electrodes, separable from the conductivity cell, comprised two parallel platinum plates about 0·8 cm. square and 0·8 cm. apart, spot welded to tungsten leads and protected by a glass sheath.[9] Before use the plates were coated with platinum black by Kohlrausch's method. The conductivity cell was so shaped that the volume of solution could be increased from 10 to 100 ml., and the electrode assembly was so inserted into the cell that a degree of movement could be obtained for stirring.

The cell constant was determined at 40° by measuring the resistance of 10^{-3}—10^{-4}N-potassium chloride and plotting the values against the published conductivity data. Where there were no published data at 40°, values were obtained by means of the equation quoted by Mellor.[10]

Technique.—Measurements were made in duplicate with the cells in a thermostat at 40·0° ± 0·05°, this temperature being chosen because many of the surface-active compounds in the region of the critical micelle concentration do not yield homogeneous solutions at room

[8] Cf. Miles and Shedlovsky, *J. Phys. Chem.*, 1945, **49**, 71.
[9] Winsor, *Trans. Faraday Soc.*, 1950, **46**, 762.
[10] Mellor, "A Comprehensive Treatise on Inorganic and Physical Chemistry," Longmans Green & Co., London, Vol. II, p. 551.

temperature. A small known volume (usually 10 ml.) was placed in the cell and allowed to come to thermal equilibrium for *ca.* 20 min. Its resistance was determined, and a measured volume of water at 40° was added to the cell. After a short period the resistance was again measured and further water (total 90 ml.) was added; in all about 20 readings were taken. The specific conductivity of the solution was calculated and the values, after correction for the conductivity of water, were plotted against concentration. Straight lines were drawn through the upper and the lower part of the plot; the point of intersection showed the concentration at which micelles are formed.[11] The type of graph obtained is shown in Fig. 1 for the isomeric sodium C_{14}-alkyl sulphates. For compounds of lower molecular weight (*e.g.*, sodium octyl and 1-pentylhexyl sulphate) there is more pronounced curvature near the point of intersection, indicating probably that in this region the micellar size is indefinite. Since the existence of a curved portion is held to indicate a growth of micelles over the small concentration range involved, it follows that the point of intersection (see above) represents a concentration at which micelles are approximately half-developed.

Results and Discussion

Table 1 gives the critical micelle concentrations of the sodium alkyl sulphates at 40°, each value being the average of duplicate determinations. Here and elsewhere, L denotes the number of carbon atoms in the "chain" R·CH·R', and P denotes the position of the $NaO{\cdot}SO_2{\cdot}O$–group along that chain.

Table 1. *Critical micelle concentrations (cmc) of sodium alkyl sulphates at 40°.*

P	L	cmc (mM)	P	L	cmc (mM)	P	L	cmc (mM)
1	8	136	3	11	28·9	6	11	83
	12	8·65		14	4·30		16	2·35
	14	2·40		15	2·20		18	0·72
	16	0·58						
	18	$0{\cdot}16_5$	4	14	5·15	7	13	19·3
				16	1·72		14	9·70
2	8	180		18	0·45			
	10	49·5				8	15	6·65
	13	6·50	5	14	6·75		16	4·25
	14	3·30		15	3·40			
	15	1·71		19	0·33	9	17	2·35
	17	0·49						
	18	0·26				10	19	0·94
						15	29	0·08

Comparison with Other Data.—Wijga [12] has determined the critical micelle concentrations (cmc) of the isomeric sodium C_{14}-alkyl sulphates by conductivity measurements at 60°. His results are higher than those given in Table 1 by a factor which varies between 1·13 and 1·19 (average 1·17); the temperature coefficient (α) is therefore 0·0085 where $(\text{cmc})_t/(\text{cmc})_{40} = 1 + \alpha(t - 40)$. Winsor's results for the same compounds by the spectral (dye) method at room temperature [5] differ considerably, the values given by the two methods varying systematically with the position of the sulphate group. For sodium *n*-tetradecyl sulphate the dye method gives the lower value and for sodium 1-hexyloctyl sulphate the higher value, whereas the values are about equal for the 1-propylundecyl compound. Thus the spectral (dye) method needs to be used with care. For example the critical micelle concentration of a commercial mixture of sodium alkyl sulphates free from inorganic salt, determined by the dye method, is approximately that of the component having the lowest value. This appears to indicate that with such mixtures the dye tends to remain associated with the micellar form of the alkyl sulphate until the last micelles disappear with increasing dilution. The conductivity–concentration curves for these mixtures of alkyl sulphates show no definite break, indicating that micelles are formed over a relatively wide concentration range.

Apart from the isomeric C_{14} compounds and sodium 1-ethylnonyl sulphate [13] (by the spectral method), only the primary alkyl sulphates have been examined previously. Some

[11] Wright, Abbott, Sivertz, and Tartar, *J. Amer. Chem. Soc.*, 1939, **61**, 549.
[12] Wijga, personal communication.
[13] Winsor, "Solvent Properties of Amphiphilic Compounds," Butterworths, London, 1954.

TABLE 2. *Comparison of critical micelle concentrations (cmc) (10^{-3}M) of sodium primary alkyl sulphates.*

Method	Temp.	No. of carbon atoms (L) 8	12	14	16	18	Ref.
Spectral (Dye)	26—35°	—	6·1, 6·5	—	0·40	—	1
Surface tension	60	—	8	2·0	0·43	0·17	4
Conductivity	60	—	7·6	2·6	1·0	0·4	2
,, ...	25	130	8·1	—	—	—	14
,, ...	25—40	—	9·0	2·5	—	—	3
Present work	40	135	8·65	2·40	0·58	0·17	—
Temp. coeff. (%)	—	—	1·3	2·2	1·0	0·35	4

comparisons are given in Table 2 : after allowance for the effect of temperature, the previous results are all in general lower than the present values. Since the probable impurities in the system in general lower the critical micelle concentration, the present higher results may be due to the more rigorous purification.

Variation of Critical Micelle Concentration within Homologous and Isomeric Series.—Fig. 2, where the number (L) of carbon atoms is plotted against the logarithm of the critical

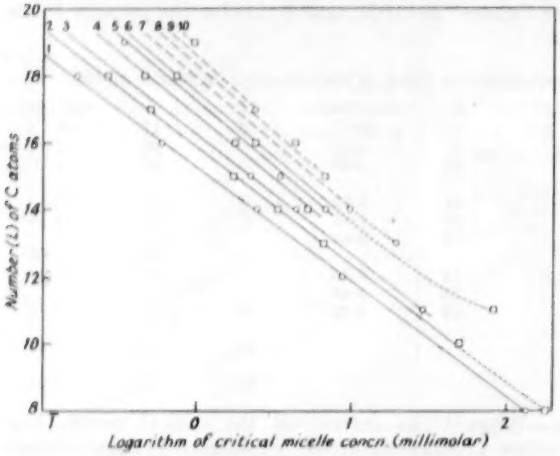

FIG. 2. *Logarithms of critical micelle concentrations of sodium alkyl sulphates, arranged in homologous series.*

———, Derived statistically.
— —, Obtained by extrapolation.
– – –, Non-linear relation.

The numbers attached to the individual curves denote P (cf. Fig. 1).

micelle concentrations (cf. Table 1), shows that lines drawn through the points representing homologous series are straight except at their lower ends. The full lines represent the statistical equations derived from the numerical data. The broken lines for the series where the sulphate group is at position 7—10 along the chain were obtained by reading from the full lines the values of L at critical micelle concentrations of 1 and 10 mmoles $l.^{-1}$ and plotting them against P (the numerical position of the sulphate group along the chain). Values of L for P = 7—10 were then obtained by extrapolation, the critical micelle concentration of sodium 1-nonyldecyl sulphate being used as reference point. All the straight lines can be represented by equations

$$\log_{10}(\text{cmc}) = a - bL \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Values of the constants for the separate homologous series are given in Table 3. It will be noted from Fig. 2 that the slope $1/b$ of the lines increases somewhat as the sulphate group is shifted towards the middle of the chain, indicating a spread in critical micelle values with increase in chain length. The values of a show no systematic trend, and the results are probably best represented by considering a as approximately constant for all values of P. When the alkyl sulphates are arranged in isomeric series, for a given value of L, log cmc can be approximately represented by $a' - b'P$.

[14] Haffner, Piccione, and Rosenblum, *J. Phys. Chem.*, 1942, **46**, 662.

TABLE 3. *Constants b (slope) and a (intercept) in eqn. 1 (empirical values).*

Determined statistically:			Obtained by extrapolation:		
P	*b*	*a*	*P*	*b*	*a*
1	0·294	4·49	7	0·256	4·59
2	0·286	4·53	8	0·251	4·58
3	0·280	4·55	9	0·245	4·55
4	0·266	4·47	10	0·240	4·52
5	0·258	4·44			
6	0·270	4·72			

It may be noted that the equation of the type (1) in which L is replaced by the overall length of the surface-active ion, found by Klevens [15] to hold for simple uni-univalent amphiphilic salts in general irrespective of the nature of the hydrophilic group, must apply only to those homologous series comprising compounds in which the hydrophilic group is in the terminal position. If Klevens's relation were applicable to all homologous series then, for example, sodium *n*-tetradecyl, 1-methyltetradecyl, and 1-ethyltetradecyl sulphate would have approximately the same critical micelle concentration since the effective length $(L - P)$ of each of these amphiphilic ions is the same. Reference to Fig. 2 shows that in fact sodium *n*-tetradecyl, 1-ethyltridecyl, 1-pentylundecyl, and 1-octylnonyl sulphate have approximately the same critical micelle concentrations.

Although the relation between members of a homologous series appears to be linear for compounds containing more than 10 carbon atoms, the possibility exists that with more than 19 carbon atoms the lines of Fig. 2 may again become convex. Thus, although the critical micelle concentration of sodium 1-tetradecylpentadecyl sulphate, calculated from equation (1) with values of a and b extrapolated from the data of Table 3, is *ca.* $0{\cdot}5 \times 10^{-4}$M, and thus in reasonable agreement with the experimental value ($0{\cdot}8 \times 10^{-4}$M), the latter is probably not within the range covered by the linear equation.

Structure of Micelles.—According to McBain,[16] when long-chain ions form clusters, the equivalent conductivity of the solution should be increased. If n single long-chain ions form a homoionic micelle, it can be deduced that the equivalent conductivity of the micellar ion should be $n^{2/3}$ times that of the single ions. The fact that the equivalent conductivity of amphiphilic salt solutions usually decreases above the critical micelle concentration has been explained as due to the inclusion within the micelle of ions of opposite charge (gegenions) to that of the long-chain ions. The number of these gegenions in relation to the number of long-chain ions must therefore be a determining factor for the equivalent conductivity of amphiphilic salts above the critical micelle concentration. The relations to be expected may be considered by using Hartley's model for the micelle, which is probably a fairly accurate representation of micellar form at concentrations not greatly above the critical micelle concentration.

If the micellar ion is composed of n long-chain ions and m gegenions:

$$n\mathrm{NaX} \rightleftharpoons n\mathrm{Na} + n\mathrm{X} \rightleftharpoons (\mathrm{X}_n\mathrm{Na}_m)^{n-m} + (n - m)\mathrm{Na}$$

the specific conductivity of a solution of amphiphilic salt NaX at concentration c above the critical micelle concentration c_o may then be regarded as divisible into three components: that due to the single ions at the critical micelle concentration, that due to the micellar ions, and that due to the sodium ions in excess.

The specific conductivity κ at concentration c may be written in the form

$$1000\kappa = c_o(\Lambda_{\mathrm{Na}} + \Lambda_{\mathrm{X}}) + \frac{c - c_o}{n}\Lambda_{\mathrm{mic}} + (c - c_o)\frac{(n - m)}{n}\Lambda_{\mathrm{Na}}$$

where Λ_{Na}, Λ_{X}, and Λ_{mic} are the equivalent conductivities of the Na, X, and micellar ions. If the specific conductivity at the critical micelle concentration is denoted by κ_o, this equation becomes equation (2):

[15] Klevens, *J. Amer. Oil Chemists' Soc.*, 1953, **30**, 74.
[16] McBain, *Trans. Faraday. Soc.*, 1913, **9**, 99; Alexander, "Colloid Chemistry," Reinhold Publ. Corp., New York, 1944, Vol. V, p. 102.

$$1000\,\frac{\kappa - \kappa_0}{c - c_0} = \frac{1}{n}\Lambda_{mic} + \frac{n-m}{n}\Lambda_{Na} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

An approximate value of n can be calculated as follows: [17]

Volume of hydrocarbon interior of micelle $= (4/3)\pi l^3$ where l is the length (Å) of the longer portion of the hydrocarbon chain attached to the sulphate group. The volume of 1 molecule of hydrocarbon of molecular weight M and density $d = 10^{24}M/Nd$, where N is Avogadro's number. Hence the number of long-chain ions in the micelle

$$n = \frac{4}{3}\pi l^3\, Nd/10^{24}M \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Λ_{mic} can be obtained as follows:

It can be deduced in conjunction with Stokes's law that the conductance of an ion in unit electrical field is proportional to the (charge)^2 divided by the radius of the ion (assumed spherical). Hence when n long-chain ions form a micelle of charge $(n - m)$ the conductivity is given by

$$\Lambda_{mic}/\Lambda_X = (n-m)^2/n^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Now $\Lambda_{Na} + \Lambda_X = 1000\kappa_0/c_0$, which is the slope S_1 of the specific conductivity–concentration curve below the critical micelle concentration, and the left-hand side of eqn. 2 is the slope S_2 above this concentration. It follows therefore from eqns. 2 and 4 that

$$1000S_2 = \frac{(n-m)^2}{n^{4/3}}(1000S_1 - \Lambda_{Na}) + \frac{n-m}{n}\Lambda_{Na} \quad . \quad . \quad . \quad . \quad (5)$$

At the low concentrations employed, Λ_{Na} may be taken as the value at infinite dilution; at 40° this is 66 (Glasstone [18]). Hence m can be evaluated from the quadratic eqn. 5. Table 4 gives the values of n calculated from eqn. 3 and those of m, the positive values only being considered.

TABLE 4. *Number of long-chain ions (n) and of gegenions (m) forming micelles, calculated from the slopes of the conductivity–concentration graphs below and above the critical micelle concentration (S_1 and S_2 respectively).*

P	L	$1000S_1$	$1000S_2$	n	m/n	m	P	L	$1000S_1$	$1000S_2$	n	m/n	m
1	8	86	50	17	0·685	12	5	14	77	49	21	0·532	11
	12	96	40	40	0·744	30		15	89	63	25	0·579	15
	14	97	40	55	0·766	42		19	92	65	51	0·657	34
	16	106	45	74	0·791	59							
	18	75	43	94	0·664	63	6	11	88	76	5	0·312	2
								16	88	67	24	0·556	13
2	8	87	53	11	0·536	6		18	101	77	36	0·629	23
	10	86	54	20	0·580	12							
	13	88	46	37	0·682	25	7	13	88	64	7	0·434	3
	14	103	46	45	0·750	34		14	107	73	11	0·544	6
	15	106	51	52	0·752	39							
	17	103	43	69	0·779	54	8	15	89	68	10	0·455	5
	18	103	42	79	0·796	63		16	84	71	13	0·427	6
3	11	93	57	18	0·596	11	9	17	97	76	12	0·491	6
	14	79	46	35	0·667	23							
	15	106	56	42	0·720	30	10	19	146	73	16	0·523	9
4	14	81	50	27	0·588	16	15	29	126	59	34	0·789	24
	16	81	54	40	0·604	24							
	18	82	57	54	0·626	34							

The values of the ratio m/n are of the magnitude to be expected from general considerations, and their variation with increase in L (for constant P) and with increase in P (for constant L) is in accord with the properties of the model adopted. Fig. 3, a plot of n against m, shows that all the alkyl sulphates examined fall on a curve passing through the origin and nearly linear. This is the more remarkable at the lower end of the curve, for it is difficult to envisage a spherical micelle containing only 5 long-chain ions and

[17] Ward, *Proc. Roy. Soc.*, 1940, *A*, **174**, 412.
[18] Glasstone, "Electrochemistry of Solutions," Methuen, 1930, p. 69.

2 gegenions, as is apparently the case for sodium 1-pentylhexyl sulphate ($P = 6$, $L = 11$). It must be remembered however that micelle formation is a dynamic process with constant interchange of ions between micellar and intermicellar states, the micelle itself being a statistical aggregate. The only serious anomaly is the value of m for the n-octadecyl

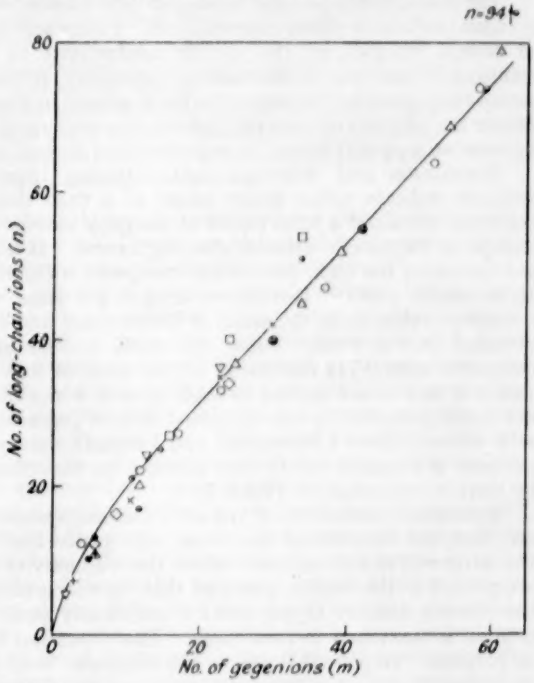

FIG. 3. *Micellar composition of sodium alkyl sulphates and sodium alkane-1-sulphonates.*

○, Sulphonates (Wijga [14]) ($P = 1$).

Sulphates: ◒, $P = 1$.
△, $P = 2$.
×, $P = 3$.
□, $P = 4$.
◑, $P = 5$.
▽, $P = 6$.
+, $P = 7$.
●, $P = 8$.
◇, $P = 9$, 10, 15.

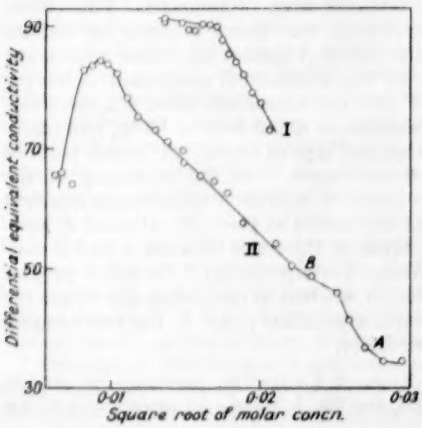

FIG. 4. *Equivalent conductivity of sodium n-octadecyl (I) and 1-tetradecylpentadecyl sulphate (II).*

compound, which is low owing to the abnormally low value found for the slope of the conductivity–concentration plot below the critical micelle concentration. Of particular interest is the value for sodium 1-tetradecylpentadecyl sulphate; despite its low critical micelle concentration and exceptional behaviour at very low concentrations (see below), at concentrations appreciably above the critical micelle concentration its micelles show similar behaviour to those of other alkyl sulphates. Also included in Fig. 3 are data

calculated from the slopes of the conductivity–concentration curves for sodium alkanesulphonates determined by Wijga.[12] Despite the fact that his measurements were made at 60° (Λ_{Na} is here taken as 84) the points for the sulphonates lie very close to the curve for the sulphates.

The micellar composition envisaged here cannot, without further proof, be applied to systems containing added inorganic salt. Tartar and his co-workers [11] show that the effect of sodium chloride on the specific conductivity of sodium dodecylbenzenesulphonate solutions is, *inter alia*, to decrease S_2 appreciably, although S_1 is almost unaltered. Eqn. 5 shows that, provided the rest of the terms remain unaltered, a decrease in S_2 will increase m. Hence the addition of inorganic cations to a solution of anionic amphiphilic salt appears to increase m, as would indeed be expected from general considerations.

Hutchinson and Melrose's light-scattering experiments [19] with sodium *n*-dodecyl sulphate indicate rather larger values of n than those obtained by calculation. Their solutions contained a large excess of inorganic cations which, they believed, decreased the charge on the micelle without affecting its size. It is probable however that their values are somewhat too high, particularly compared with other estimates quoted in their paper. In an earlier paper [20] Hutchinson applied the value $n = 80$ which he found for sodium *n*-dodecyl sulphate to the slope of Lottermoser and Püschel's conductivity curves,[3] and obtained $m/n = 0{\cdot}825$. Using the value $n = 80$ in eqn. 5 we obtain $m/n = 0{\cdot}786$, compared with 0·744 calculated on the basis of $n = 40$. It appears therefore that the values of m/n do not depend strongly upon n, which can be varied within wide limits without much alteration in the calculated ratio of gegenions to long-chain ions. The value of m/n obtained from Lottermoser and Püschel's data may possibly be high owing to the presence of inorganic salt in their solution, for the critical micelle concentration determined by them is somewhat low (Table 2).

Equivalent Conductivity of Sodium 1-Tetradecylpentadecyl Sulphate.—McBain has pointed out that, not only should homoionic aggregation lead to an increase in conductivity, but the latter will also be increased above the conductivity at infinite dilution even if gegenions are present in the micelle, provided that the excess charge ($n - m$) is sufficiently high, *i.e.*, the relative number of gegenions is sufficiently small. The Λ–c curve should therefore contain a maximum in such cases. This effect has been observed for several cationic amphiphilic compounds,[21] and as the molecular weight of the compound, is increased the maximum occurs at a lower concentration and becomes more pronounced. This effect, hitherto unreported for anionic amphiphilic compounds, was found to occur for sodium 1-tetradecylpentadecyl sulphate. Fig. 4 shows the plot of Λ against the square root of the concentration for this salt and, for comparison, for the *n*-octadecyl compound, Λ having been corrected for the conductivity of the water. For the former salt there is a sharp rise in Λ at about $0{\cdot}6 \times 10^{-4}$M, passing through a maximum at about $0{\cdot}85 \times 10^{-4}$M, and thereafter falling continuously; the latter salt gives a normal type of curve. A further point of interest in this graph lies in the low-conductivity region. At the beginning of the experiment at the higher concentrations the solution of sodium 1-tetradecylpentadecyl sulphate in water was turbid and on dilution was still turbid at point A; at point B however it was visually clear. The existence of the break in the curve between A and B may therefore be held to mark a phase change; on Winsor's interpretation [13] the salt is present at the lower concentrations as an S_1 isotropic solution, whereas at concentrations above the break the S_1 solution is in equilibrium with a liquid-crystalline phase G, the two forming together a stable emulsion which shows visible turbidity.

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Thornton-Le-Moors, Chester. [*Received, August 16th*, 1955.]

[19] Hutchinson and Melrose, *Z. phys. Chem.* (*Frankfurt*), 1954, **2**, 363.
[20] Hutchinson, *J. Colloid Sci.*, 1954, **9**, 191.
[21] McDowell and Kraus, *J. Amer. Chem. Soc.*, 1951, **73**, 2173; Ralston, Eggenberger, and DuBrow, *ibid.*, 1948, **70**, 977.

118. *A Quantitative Study of the Autoxidation Products of Oleic Acid.*

By George King.

Oleic acid has been oxidised with gaseous oxygen at room temperature, at 49° and at 78°, with and without a cobalt catalyst. Oxidation of the pure acid at room temperature is very slow, the principal products being oxo-acids, but in the presence of cobalt relatively high yields of 8- and 11-oxo-oleic acids,* epoxide, and cleavage products are obtained.

At 49° and 78° the oxidations follow the same general patterns as those already observed with elaidic acid but, in the absence of a catalyst, derivatives of both forms of 9 : 10-dihydroxystearic acid are produced, whereas elaidic acid appears to give only the higher-melting, *erythro*-form.

A detailed quantitative study of the autoxidation of elaidic acid has already been made,[1] and the present communication records similar work on oleic acid, prepared from the commercial redistilled acid by low-temperature crystallisation from acetone.[2]

When dispersed on filter paper and exposed to air at room temperature oleic acid was oxidised extremely slowly, giving about 4% of conjugated unsaturated keto-acids (8- and 11-oxo-oleic),* 8% of other oxo-acids, 2—3% of peroxides, and little or no epoxide or ketol after 2 years (Tables 1 and 7). When oxygen was bubbled through oleic acid containing 0·5% of cobalt for 28 days, however, a relatively high content (15%) of conjugated unsaturated ketonic acids was found, together with appreciable amounts of other oxo-acids, epoxide, ketol, and cleavage products, but very little dihydroxystearic acid was obtained on saponification (Tables 2 and 8). As in other cobalt-catalysed autoxidations of oleic and elaidic acids the peroxide concentration remained quite low.

In experiments at 49° the course of oxidation closely resembled that observed with elaidic acid [1] under similar conditions, but the formation of dihydroxystearic esters and of oxo-acids other than 8- and 11-oxo-acids was greater during the earlier stages than in the case of elaidic acid. The concentration of these other oxo-acids (whose identity has not been established) fell sharply, however, during the later stages of non-catalytic oxidations, suggesting that they are less stable than the corresponding elaidic acid derivatives. Prolonged oxidation in the presence of cobalt gave much higher yields of fission products (volatile acids such as nonanoic, and water-soluble acids such as azelaic) than uncatalysed oxidations or comparable oxidations of elaidic acid (Tables 9 and 10) (cf. Ellis [3]).

The similarities between the oxidations of oleic acid and elaidic acid at 78° were equally striking, and in both cases, in the absence of a catalyst, peroxides reached a peak value before the other products. A notable difference was observed, however, in non-catalytic experiments, the concentration of combined dihydroxystearic acid remaining below 7% after 8 days in the case of oleic acid, whereas with elaidic acid it exceeded 27%. On the other hand, in the presence of cobalt the concentrations of dihydroxystearic acid were about equal, but the amounts of fission products were much higher in the case of oleic acid (Table 12). The dihydroxystearic acid isolated after hydrolysis of the products resulting from the non-catalytic autoxidation of oleic acid consisted of a mixture of the two stereo-isomeric forms, m. p.s 95° and 132° (cf. Skellon; [4] Feuell and Skellon [5]). This may explain the low values of dihydroxystearic acid isolated in some cases (see, *e.g.*, Table 7), since the greater solubility of the lower-melting (*threo*) form renders its quantitative isolation much more difficult. In the presence of cobalt only the *erythro*-form has so far been observed.

Although no free ketol-acid has actually been isolated from autoxidised oleic or elaidic acid, Feuell and Skellon [5] have recently separated a small quantity of the 9 : 10-hydroxy-oxostearic acids from the products of the autoxidation of propyl oleate in the presence of 0·05% of uranium at 120°.

* $CO_2H = 1$. In *J.*, 1954, 2114, these acids were named as, *e.g.*, η- and κ-oxo-oleic acid.

[1] King, *J.*, **1954**, 2114.
[2] Brown and Shinowara, *J. Amer. Chem. Soc.*, 1937, **59**, 6.
[3] Ellis, *Biochem. J.*, 1936, **30**, 753.
[4] Skellon, *J. Soc. Chem. Ind.*, 1931, **50**, 382T.
[5] Feuell and Skellon, *J.*, 1954, 3414.

TABLE 1. *Autoxidation at room temperature without a catalyst.*

Time (months)	3	6	12	24
Physical condition	Pale yellow oil	Pale yellow oil	Yellow oil	Rather viscous oil
Reduction of Fehling's soln.	None	None	Trace	Weak
Equiv. wt.	286	284	295	304
Iodine value	79	78	63	59
$E^{1\%}_{1\,cm.}$ at 224 mμ	8·7	11·3	19·1	30·0
Neutral, steam-volatile oil (mainly nonanal and nonan-2-one) (%)	0·31	0·37	0·55	0·48
Volatile oil (nonanal and nonanone) resulting from hydrolysis on distiln. with 0·5N-NaOH (%)	Trace	0·02	1·20	1·15
Nonanal on distiln. of the residual solution from the above hydrolysis with KIO_4 at pH 8·0 (%)	0·40	0·51	1·50	1·64
Saponification value	9	10	41	46
Nonanal resulting from oxidn. with KIO_4 at pH 8·0 (%)	0·18	0·18	0·0	0·0
Carbonyl (%)	0·49	0·68	0·87	1·24
Oxiran-O (%)	0·0	0·0	0·0	0·0
Active O (%)	0·04	0·06	0·13	0·13
Steam-volatile acids, mequiv. (%)	10	23	54	28
Non-volatile, water-soluble acids, mequiv. (%)	6	7	25	25

TABLE 2. *Autoxidation at room temperature in the presence of* 0·5% *of cobalt.*

Time (days)	1	2	4	7	14	28
Physical condition	Oil	Oil	Oil	Oil	Rather viscous oil	Viscous oil
Reduction of Fehling's soln.	None	None	Trace	Slight	Slight	Weak
Equiv. wt.	285	284	277	270	254	232
Iodine value	78	74	66	61	50	32
$E^{1\%}_{1\,cm.}$ at 224 mμ	25·0	46·4	75·9	82·1	94·1	88·8
Neutral, steam-volatile oil (mainly nonanal and nonan-2-one) (%)	Trace	Trace	0·20	0·35	0·35	0·35
Volatile oil (nonanal and nonanone) resulting from hydrolysis on distiln. with 0·5N-NaOH (%)	1·32	2·65	4·61	5·31	6·22	5·50
Nonanal on distiln. of the residual solution from the above hydrolysis with KIO_4 at pH 8·0 (%)	Trace	0·34	0·50	1·13	1·96	2·78
Saponification value	7	10	17	22	33	45
Nonanal resulting from oxidn. with KIO_4 at pH 8·0 (%)	0·0	0·22	0·36	0·51	0·61	1·07
Carbonyl (%)	0·69	1·22	2·02	2·26	2·63	3·05
Oxiran-O (%)	0·10	0·18	0·24	0·40	0·38	0·59
Active O (%)	0·05	0·06	0·08	0·09	0·08	0·11
Steam-volatile acids, mequiv.	4	—	—	18	23	64
Non-volatile, water-soluble acids, mequiv. (%)	9	—	—	41	67	110

TABLE 3. *Autoxidation at* 49° *without a catalyst.*

Time (days)	7	14	21	28
Physical condition	Oil	Oil	Oil	Slightly viscous
Reduction of Fehling's soln.	None	Trace	Weak	Weak
Equiv. wt.	289	308	310	310
Iodine value	81	70	57	42
$E^{1\%}_{1\,cm.}$ at 224 mμ	10·1	27·3	41·3	52·1
Neutral, steam-volatile oil (mainly nonanal and nonan-2-one) (%)	0·36	0·95	1·53	1·62
Volatile oil (nonanal and nonanone) resulting from hydrolysis on distiln. with 0·5N-NaOH (%)	0·53	1·90	3·16	3·88
Nonanal on distiln. of the residual solution from the above hydrolysis with KIO_4 at pH 8·0 (%)	0·84	3·22	4·41	4·72
Saponification value	19	34	54	70
Nonanal resulting from oxidn. with KIO_4 at pH 8·0 (%)	0·08	0·46	0·53	0·98
Carbonyl (%)	0·56	1·41	1·78	1·79
Oxiran-O (%)	0·24	0·28	0·51	0·51
Active O (%)	0·24	0·44	0·55	0·47
Steam-volatile acids, mequiv. (%)	15	25	27	31
Non-volatile, water-soluble acids, mequiv. (%)	5	20	35	44

Considerable amounts of carbon dioxide were evolved in catalysed oxidations at 49° and at 78° (cf. Ellis; [6] Skellon and Thruston [7]) and its formation was increased both absolutely and relatively to that of formic acid by the catalyst (Table 13). Probably formic acid is itself oxidised under these conditions. The formation of formic acid from pure oleic acid (which may well involve preliminary α-oxidation) has been reported previously,[4] but it is known to result also from the catalysed autoxidation of saturated compounds such as stearic acid and hexadecane.[8]

TABLE 4. *Autoxidation at 49° in the presence of 0·5% of cobalt.*

Time (hr.)	8	16	24	48	72	96	168
Physical condition	Oil	Oil	Oil	Rather viscous Few crystals	Some crystals	Pasty	Pasty
Reduction of Fehling's soln.	None	None	Slight	Moderate	Moderate	Moderate	Rather strong
Equiv. wt.	287	282	274	263	253	220	194
Iodine value	84	73	62	51	39	16	9
$E^{1\%}_{1\,cm.}$ at 224 mμ	17·3	44·8	68·1	75·2	71·4	46·6	20·2
Neutral, steam-volatile oil (mainly nonanal and nonan-2-one) (%)	0·20	0·43	0·74	0·80	0·86	1·13	0·87
Volatile oil (nonanal and nonanone) resulting from hydrolysis on distiln. with 0·5N-NaOH (%)	0·75	3·03	4·44	4·74	4·73	2·46	0·91
Nonanal on distiln. of the residual solution from the above hydrolysis with KIO_4 at pH 8·0 (%)	0·22	0·85	1·56	2·47	3·04	3·62	4·78
Saponification value	3	14	21	32	44	80	99
Nonanal resulting from oxidn. with KIO_4 at pH 8·0 (%)	0·14	0·21	0·15	0·40	0·56	1·10	1·49
Carbonyl (%)	0·49	1·08	1·67	2·04	2·32	2·09	2·01
Oxiran-O (%)	0·19	0·33	0·45	0·75	0·91	0·87	0·45
Active O (%)	0·02	0·06	0·04	0·04	0·04	0·11	0·10
Steam-volatile acids, mequiv. (%)	9	21	36	48	55	100	121
Non-volatile, water-soluble acids, mequiv. (%)	12	15	33	52	68	135	193

TABLE 5. *Autoxidation at 78° without a catalyst.*

Time (days)	1	2	4	6	8
Physical condition	Oil	Oil	Rather viscous	Rather viscous	Viscous some crystals
Reduction of Fehling's soln.	None	Trace	Weak	Fairly strong	Strong
Equiv. wt.	283	296	307	310	297
Iodine value	81	67	38	25	15
$E^{1\%}_{1\,cm.}$ at 224 mμ	7·6	21·3	45·5	44·3	32·2
Neutral, steam-volatile oil (mainly nonanal and nonan-2-one) (%)	0·13	0·24	0·76	0·69	0·68
Volatile oil (nonanal and nonanone) resulting from hydrolysis on distiln. with 0·5N-NaOH (%)	0·24	1·18	2·61	2·05	1·56
Nonanal on distiln. of the residual solution from the above hydrolysis with KIO_4 at pH 8·0 (%)	0·24	0·56	4·18	4·48	4·98
Saponification value	5	23	70	102	134
Nonanal resulting from oxidn. with KIO_4 at pH 8·0 (%)	0·12	0·88	0·84	1·18	1·92
Carbonyl (%)	0·44	0·94	1·84	2·14	1·99
Oxiran-O (%)	0·15	0·44	0·68	0·51	0·12
Active O (%)	0·19	0·44	0·33	0·15	0·14
Steam-volatile acids, mequiv. (%)	14	24	41	52	66
Non-volatile, water-soluble acids, mequiv. (%)	4	16	48	70	83

The iodine and saponification values were similar to those obtained with elaidic acid under comparable conditions. It is significant that the high saponification value found after oleic acid had been oxidised at 78° for 8 days without a catalyst was not associated with a particularly high content of dihydroxystearic acid (Tables 5 and 11; cf. elaidic acid)

[6] Ellis, *Biochem. J.*, 1950, **46**, 129; 1932, **26**, 791.
[7] Skellon and Thruston, *J.*, 1949, 1630.
[8] Salway and Williams, *J.*, 1922, 1343.

TABLE 6. *Autoxidation at 78° in the presence of 0·5% of cobalt.*

Time (hr.)	4	8	12	16	32
Physical condition	Oil	Oil	Few crystals	Viscous; some crystals	Semi-crystalline
Reduction of Fehling's soln.	Trace	Slight	Moderate	Moderate	Fairly strong
Equiv. wt.	292	284	273	259	204
Iodine value	78	60	45	35	14
$E^{1\%}_{1\,cm.}$ at 224 mμ	25·9	48·5	59·5	49·7	19·7
Neutral, steam-volatile oil (mainly nonanal and nonan-2-one) (%)	0·33	0·74	0·85	0·84	0·88
Volatile oil (nonanal and nonanone) resulting from hydrolysis on distiln. with 0·5N-NaOH (%)	1·45	2·87	2·89	2·69	0·81
Nonanal on distiln. of the residual solution from the above hydrolysis with KIO_4 at pH 8·0 (%)	0·71	1·81	2·87	3·49	3·99
Saponification value	18	35	55	66	102
Nonanal resulting from oxidn. with KIO_4 at pH 8·0 (%)	0·09	0·27	0·48	0·59	1·04
Carbonyl (%)	0·58	1·42	1·86	2·06	2·12
Oxiran-O (%)	0·11	0·47	0·54	0·72	0·24
Active O (%)	0·04	0·04	0·03	0·03	0·03
Steam-volatile acids, mequiv. (%)	17	35	46	57	99
Non-volatile, water-soluble acids mequiv. (%)	10	31	53	78	155

TABLE 7. *Composition (%) of non-gaseous products obtained by autoxidation at room temperature without a catalyst.*

Time (months)	3	6	12	24
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from (*a*) $E^{1\%}_{1\,cm.}$ val.	0·3	0·7	2·2	4·2
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from (*b*) hydrolysis products	Trace	0·9	3·3	3·2
9 : 10-Ketol-acids, as $C_{18}H_{34}O_4$	1·0	1·0	0·0	0·0
Other oxo-acids, as $C_{18}H_{32}O_3$	3·3	4·7	5·8	7·9
9 : 10-Epoxystearic acid	0·0	0·0	0·0	0·0
Hydroperoxyoleic acid	0·8	1·2	2·5	2·6
Dihydroxystearic acid (combined) (*a*) KIO_4 method	Trace	0·7	4·0	4·4
Dihydroxystearic acid (combined) (*b*) isolated	0·0	0·0	0·2	0·7
Steam-volatile acids, as nonanoic	1·6	3·6	8·5	4·4
Non-volatile, water-soluble acids, as azelaic	0·6	0·7	2·4	2·3
Neutral, steam-volatile oil (mainly nonanal and nonanone)	0·3	0·4	0·5	0·5
Unchanged oleic acid (calc.)	84	81	60	52

TABLE 8. *Autoxidation at room temperature in the presence of 0·5% of cobalt.*

Time (days)	1	2	4	7	14	28
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from (*a*) $E^{1\%}_{1\,cm.}$ val.	2·8	6·7	12·2	13·4	15·6	14·6
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from (*b*) hydrolysis products	3·7	6·9	11·4	12·9	14·7	13·1
9 : 10-Ketol-acids, as $C_{18}H_{34}O_4$	0·0	1·2	2·0	2·8	3·4	6·0
Other oxo-acids, as $C_{18}H_{32}O_3$	4·5	5·0	6·8	7·2	8·3	11·3
9 : 10-Epoxystearic acid	1·9	3·4	4·5	7·4	7·0	11·0
Hydroperoxyoleic acid	0·9	1·2	1·6	1·8	1·6	2·1
Dihydroxystearic acid (combined) (*a*) KIO_4 method	0·0	0·0	0·0	0·0	0·8	1·6
Dihydroxystearic acid (combined) (*b*) isolated	0·0	0·0	0·0	0·0	0·15	0·6
Steam-volatile acids, as nonanoic	0·7	—	—	2·9	3·6	10·1
Non-volatile, water-soluble acids, as azelaic	0·9	—	—	3·8	6·3	10·4
Neutral, steam-volatile oil (mainly nonanal and nonanone)	Trace	Trace	0·2	0·3	0·3	0·3
Unchanged oleic acid (calc.)	79	70	53	46	31	8

TABLE 9. *Autoxidation at 49° without a catalyst.*

Time (days)	7	14	21	28
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from (*a*) $E^{1\%}_{1\,cm.}$ val.	0·6	3·8	6·4	8·4
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from (*b*) hydrolysis products	1·5	4·8	7·5	8·9
9 : 10-Ketol-acids, as $C_{18}H_{34}O_4$	0·4	2·6	2·9	5·5
Other oxo-acids, as $C_{18}H_{32}O_3$	4·2	6·7	6·6	2·1
9 : 10-Epoxystearic acid	4·5	5·2	9·4	9·5
Hydroperoxyoleic acid	4·7	8·7	10·8	9·2
Dihydroxystearic acid (combined) (*a*) KIO_4 method	0·6	5·7	8·1	8·5
Dihydroxystearic acid (combined) (*b*) isolated	0·0	0·0	0·5	3·6
Steam-volatile acids, as nonanoic	2·4	4·0	4·3	4·9
Non-volatile, water-soluble acids, as azelaic	0·5	1·9	3·3	4·1
Neutral, steam-volatile oil (mainly nonanal and nonanone)	0·4	0·9	1·5	1·6
Unchanged oleic acid (calc.)	82	60	42	28

TABLE 10. *Autoxidation at 49° in the presence of 0·5% of cobalt.*

Time (hr.)	8	16	24	48	72	96	168
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from ... (*a*) $E^{1\%}_{1\,cm.}$ val.	1·4	6·5	10·8	12·2	11·5	6·9	2·0
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from ... (*b*) hydrolysis products...	2·1	7·2	10·1	10·8	10·7	6·1	2·5
9 : 10-Ketol-acids, as $C_{18}H_{34}O_4$	0·8	1·2	0·8	2·2	3·1	6·1	8·3
Other oxo-acids, as $C_{18}H_{32}O_3$	2·6	2·9	4·5	5·7	8·3	7·2	9·7
9 : 10-Epoxystearic acid	3·5	6·2	8·3	14·0	17·0	16·2	8·4
Hydroperoxyoleic acid	0·5	1·1	0·8	0·8	0·8	2·1	2·0
Dihydroxystearic acid (combined) (*a*) KIO_4 method	0·0	Trace	2·1	3·5	4·4	4·5	6·8
Dihydroxystearic acid (combined) (*b*) isolated	0·0	0·0	Trace	0·8	1·3	3·9	4·6
Steam-volatile acids, as nonanoic	1·5	3·4	5·7	7·7	8·7	15·8	19·2
Non-volatile, water-soluble acids, as azelaic	1·1	1·4	3·1	4·9	6·4	12·7	18·1
Neutral, steam-volatile oil (mainly nonanal and nonanone)	0·2	0·4	0·7	0·8	0·9	1·1	0·9
Unchanged oleic acid (calc.)	89	71	54	39	24	3	1

TABLE 11. *Autoxidation at 78° without a catalyst.*

Time (days)	1	2	4	6	8
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from ... (*a*) $E^{1\%}_{1\,cm.}$ val.	0·2	2·7	7·2	6·9	4·7
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from ... (*b*) hydrolysis products...	0·7	3·1	6·4	5·2	4·1
9 : 10-Ketol-acids, as $C_{18}H_{34}O_4$	0·7	4·9	4·7	6·5	10·6
Other oxo-acids, as $C_{18}H_{32}O_3$	3·6	2·2	6·3	7·0	4·9
9 : 10-Epoxystearic acid	2·8	8·1	12·7	9·6	2·2
Hydroperoxyoleic acid	3·7	8·3	6·4	3·0	2·7
Dihydroxystearic acid (combined) (*a*) KIO_4 method	0·0	0·0	6·7	6·7	6·5
Dihydroxystearic acid (combined) (*b*) isolated	0·0	0·3	4·0	5·4	7·0
Steam-volatile acids, as nonanoic	2·3	3·8	6·5	8·2	10·4
Non-volatile, water-soluble acids, as azelaic	0·4	1·5	4·6	6·6	7·8
Neutral, steam-volatile oil (mainly nonanal and nonanone)	0·1	0·2	0·8	0·7	0·7
Unchanged oleic acid (calc.)	83	62	24	11	5

TABLE 12. *Autoxidation at 78° in the presence of 0·5% of cobalt.*

Time (hr.)	4	8	12	16	32
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from ... (*a*) $E^{1\%}_{1\,cm.}$ val.	3·0	7·2	9·3	7·4	1·9
8- and 11-Oxo-oleic acids, $C_{18}H_{32}O_3$, deduced from ... (*b*) hydrolysis products ...	3·8	6·9	7·0	6·5	2·2
9 : 10-Ketol-acids, as $C_{18}H_{34}O_4$	0·5	1·5	2·7	3·3	5·8
Other oxo-acids, as $C_{18}H_{32}O_3$	2·0	4·9	6·2	9·5	13·3
9 : 10-Epoxystearic acid	2·1	8·7	10·0	13·4	4·4
Hydroperoxyoleic acid	0·8	0·7	0·6	0·6	0·6
Dihydroxystearic acid (combined) (*a*) KIO_4 method	0·4	2·5	4·5	5·6	6·2
Dihydroxystearic acid (combined) (*b*) isolated	Trace	0·3	1·2	2·2	7·9
Steam-volatile acids, as nonanoic	2·6	5·6	7·3	9·0	15·7
Non-volatile, water-soluble acids, as azelaic	1·0	2·9	5·0	7·3	14·6
Neutral, steam-volatile oil (mainly nonanal and nonanone)	0·3	0·7	0·8	0·8	0·9
Unchanged oleic acid (calc.)	81	54	34	22	0

TABLE 13. *Gaseous (or vaporised) products per 100 g. of oleic acid* (a) *alone,* (b) *with 0·5% of cobalt.*

	Room		49°		78°	
	a	*b*	*a*	*b*	*a*	*b*
Temp.	28 days	28 days	28 days	7 days	8 days	32 hr.
CO_2 (g.)	Trace	0·72	2·23	10·5	4·71	10·3
Formic acid (g.)	Trace	0·52	0·53	0·86	1·11	0·13

TABLE 14. *Maximum observed yields (% of total non-gaseous products) of some autoxidation products of oleic acid.*

Product	Yield (%)	Co catalyst (%)	Time	Temp.
8- and 11-Oxo-oleic acids	15·6	0·5	14 days	Room
Ketol-acids (as $C_{18}H_{34}O_4$)	10·6	0	8 days	78°
Other oxo-acids (as $C_{18}H_{32}O_3$)	13·3	0·5	32 hr.	78
Epoxystearic acid	17·0	0·5	3 days	49
Dihydroxystearic acid	8·5	0	28 days	49
Hydroperoxyoleic acid	10·8	0	21 days	49
Cleavage products (such as nonanoic and azelaic acids)	37·3	0·5	7 days	49

FIG. 1. *At room temperature, with 0·5% of cobalt.*

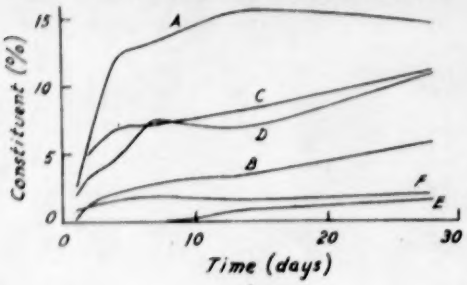
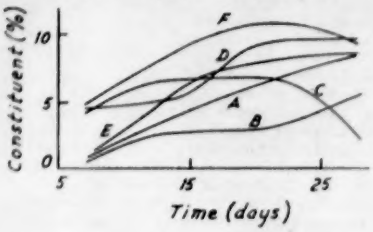


FIG. 2. *At 49°, without catalyst.*



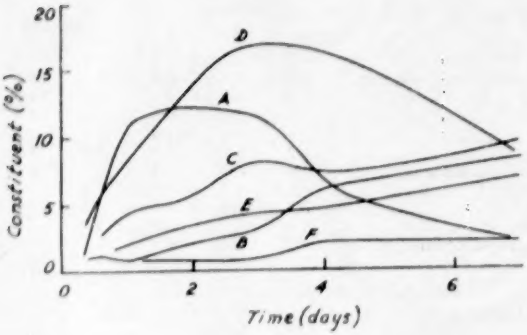


FIG. 3. *At 49°, with 0·5% of cobalt.*

FIG. 4. *At 78°, without catalyst.*

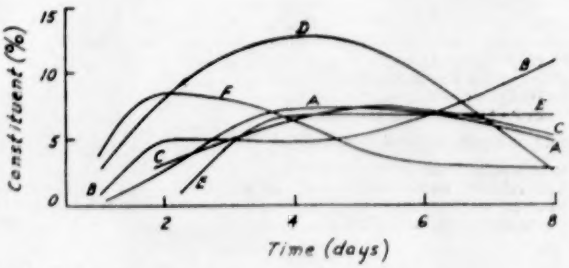
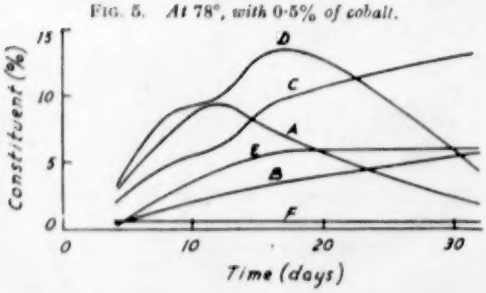


FIG. 5. *At 78°, with 0·5% of cobalt.*



Percentages refer to the total non-gaseous oxidation products (as 100%).

A, 8- *and* 11-*Oxo-oleic acids.*
B, 9 : 10-*Ketol-acids, as* $C_{18}H_{34}O_4$.
C, *Other oxo-acids, as* $C_{18}H_{32}O_3$.
D, 9 : 10-*Epoxystearic acid.*
E, *Dihydroxystearic acid (combined).*
F, *Peroxides, as hydroperoxyoleic acid.*

and could not therefore have been due solely to the hydrolysis of acyl derivatives of the latter.

The percentage compositions of the total non-gaseous products (Tables 7—12) were calculated from the analytical data as in the previous communication, but further work

remains to be done on the qualitative resolution and characterisation of the unidentified oxo- and other acids, including polymeric material, before a complete analysis is possible. The quantitative methods were substantially the same as those used for autoxidised elaidic acid, but a more accurate allowance has been made for the effect of peroxides on the carbonyl determination. In calculating the percentages of cleavage products (as nonanoic and azelaic acids) the very slight steam-volatility and water-solubility of pure oleic acid have been neglected.

Experimental

Methods.—The method of oxidation and the methods of estimation were similar to those described for elaidic acid and its autoxidation products,[1] with certain modifications mentioned below. The oleic acid used in these experiments, purified by low-temperature crystallisation from acetone, had m. p. 6—7°; equiv., 282; I val., 86—87; $E^{1\%}_{1\,cm.}$ (at 224 mμ), 6·5—8; active O, negligible.

Neutral, Steam-volatile Oil (mainly Nonanal and Nonan-2-one) and Ketol.—The product (*ca.* 4 g.) was dissolved in sufficient cold N-sodium hydroxide (20—25 ml.) and water (100 ml.), and the solution was brought to pH 8·0 (pH meter) by addition of dilute sulphuric acid and diluted to 210 ml. Of the uniform solution (or suspension), portions (100 ml.) were used for the estimation of neutral, volatile oil and of ketol as described in the previous communication.

8- and 11-Oxo-oleic Acids.—These were determined spectrophotometrically and by hydrolysis as for the corresponding elaidic acid derivatives, *trans*-11-oxoheptadec-9-ene-1-carboxylic acid, m. p. 50·5°, being used as reference compound.

Carbonyl.—The hydroxylamine hydrochloride method was used as before, but titrations of liberated acid were carried out after 5 min., 30 min., 1 hr., and subsequently every hr. for several hours. The titrations were corrected for blanks done similarly (only the carbonyl compound being omitted), and a plot made of the resulting titration values from 30 min. onwards against time. Since the carbonyl compounds react quantitatively with hydroxylamine in less than 30 min., the subsequent liberation of acid is due to the relatively slow oxidation of the reagent by the peroxides in the sample. By extrapolating the curve to zero time, therefore, the true amount of acid liberated by the carbonyl may be deduced. If this amount is T ml. of 0·1N-sodium hydroxide, then the percentage of carbonyl in the substance is $0{\cdot}28T/m$, where m is the mass taken.

It was found that the action of peroxides, present in the autoxidation products, on the hydroxylamine reagent required 24 hr. or more for completion and that 16 g. of active oxygen liberated a total of 6—7 g.-equiv. of acid. The apparent percentage of carbonyl calculated on the 30-min. titration values, needed to be corrected by about 1·5 times the percentage of active oxygen (rather than 0·875 times, as previously suggested [1]), but the figure varied considerably with different samples in keeping with the view that the peroxides are heterogeneous in type. Hence the values for carbonyl and " other oxo-acids " in autoxidised elaidic acid given in the previous paper may be a little too high, more especially in non-catalytic experiments where the peroxide content is appreciable.

9 : 10-Dihydroxystearic Acids.—Oxygen was bubbled through pure oleic acid at 78° for 8 days. The product (25 g.) was saponified by refluxing it with N-alcoholic potassium hydroxide (250 ml.) for 1·25 hr. The recovered acids, filtered from oil and washed with light petroleum, were crystallised from chloroform and fractionally crystallised from ethanol, giving *erythro*-dihydroxystearic acid (1·04 g.), m. p. and mixed m. p. 130—131°, and the *threo*-acid (1·03 g.), m. p. and mixed m. p. 93—94°.

The dihydroxy-acid from oleic acid autoxidised at 49° was also a mixture of the two isomers, but appeared to contain rather more of the *threo*-form. That from catalysed oxidations, however, consisted almost entirely of the *erythro*-form, none of the lower-melting isomer being isolated.

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119. *Five-covalent Terpyridyl Complexes of Bivalent Metals. Part I. The Stereochemistry of the Zinc, Cadmium, and Copper Compounds.*

By D. E. C. Corbridge and E. G. Cox.

The structure of terpyridylzinc chloride has been investigated by three-dimensional *X*-ray analysis in sufficient detail to determine its main stereochemical features. The lattice is molecular, the zinc atom in each $Zn(terpy)Cl_2$ molecule being linked in a distorted trigonal bipyramid to five atoms, three nitrogens at 2·2 Å and two chlorines at 2·29 Å. The distortion consists chiefly in a deflection of the two axial bonds of the bipyramid to accommodate the terpyridyl molecule, the external bonds of which are also deflected. These deflections are all in the plane of the terpyridyl molecule, which remains flat; thus, approximately the complex has two planes of symmetry intersecting in a two-fold axis which passes through the zinc atom and bisects both the central pyridine ring and the ClZnCl angle.

The corresponding cadmium and copper compounds are isomorphous with the zinc compound and although they have not been investigated in such detail there is no doubt that their structures are essentially the same. The copper compound contains two molecules of water of crystallisation accommodated apparently in holes in the structure which remain empty (and are possibly smaller) in the anhydrous zinc and cadmium lattices.

Morgan and Burstall (*J.*, 1937, 1649) prepared a number of compounds of the type $M(terpy)X_2$ where M = Ag, Cu, Pd, Pt, Zn, Cd, and Hg, terpy = ter-2-pyridyl, and X is a univalent anion. The copper, palladium, and platinum chlorides were hydrated and might conceivably therefore contain octahedral complexes, but the others were anhydrous and were formulated tentatively by Morgan and Burstall as [M(terpy)X]X which suggests a planar distribution of four valencies around M since the terpyridyl could hardly be distorted enough to span three tetrahedral positions. However, there were clearly several other possibilities to consider such as a tetrahedral configuration involving only two nitrogen atoms of the terpyridyl molecule, and these could best be discriminated by *X*-ray analysis, since the insoluble nature of the compounds made it difficult to investigate their properties in solution. We have now examined a large number of metal terpyridyl compounds by means of *X*-rays and the present paper gives the stereochemical results for $Zn(terpy)Cl_2$ and the corresponding cadmium and copper compounds, which we find to be five-co-ordinated molecular complexes.

The crystallographic constants for these and for two iodides are given in Table 1, from

Table 1. *Crystallographic data for compounds* $MX_2(terpy)$.

	Form I; space-group *Ia* or *I*2/*a*.				Form II; space-group $P2_1/a$.		
M	Zn		Cd		Zn	Cd	Cu *
X	Cl	I	Cl	I	Cl	Cl	Cl
a (Å)	13·95	14·05	14·02	14·09	16·21	16·42	16·20
b (Å)	9·12	9·62	9·35	9·92	8·25	8·22	8·26
c (Å)	11·48	11·73	11·57	11·72	10·97	11·15	10·66
β	96°	95°	96°	96°	93·5°	93°	95°
$d_{calc.}$	1·71	—	1·82	—	1·70	1·84	1·88
$d_{obs.}$	1·72	—	1·82	—	1·69	1·84	1·86
n	4	4	4	4	4	4	4

The accuracy of the above cell dimensions is about 1%.
* This compound is a dihydrate, $CuCl_2(terpy),2H_2O$.

which it will be seen that the zinc and the cadmium compound are isodimorphous, and that notwithstanding the presence of two molecules of water of crystallisation, the copper compound appears to be isomorphous with the second form of the anhydrous zinc and cadmium compounds.

These results suggest very strongly that the compounds are monomeric with four molecules of $M(terpy)X_2$ per unit cell. An arrangement of two molecules of $[M(terpy)X_2]_2$ per unit cell

is not permitted by the symmetry of the space-groups *Ia* and *I2/a* and while it would be possible in the space-group $P2_1/a$ the similarity of cell dimensions and the easy interconvertibility by recrystallisation of forms I and II suggest that they are simple isomorphs of the same molecular structure differing only in the manner of packing in the crystals. The molecules being assumed to be monomeric, the space-group symmetry does not however discriminate between molecules $[M(terpy)X_2]$, salts $[M(terpy)X]X$, and continuous structures $[M(terpy)X_2]_\infty$ in which the metal atoms achieve octahedral co-ordination by sharing X atoms. If the space-group of form *I* is *I2/a* the metal atoms must lie on two-fold axes, and this would exclude continuous structures and also structures in which only two of the three terpyridyl nitrogen atoms were co-ordinated to the metal: in spite of the absence of pyroelectric effects in the liquid-air test, form I may however have the lower symmetry *Ia* in which case no symmetry requirements are imposed in the molecule by the space-group.

After a preliminary survey of the problem we decided to carry out a structure analysis on form II of $Zn(terpy)Cl_2$ using data from the isomorphous $Cd(terpy)Cl_2$ to resolve ambiguities where necessary. The intensities of 1934 *hkl* reflections from the zinc compound were estimated visually and another 561 which should have been observed were recorded as too small to measure; about 850 of the strongest reflections were used to carry out the analysis described below. About 150 *h*0*l* intensities from the cadmium compound were measured. The structure amplitudes were calculated in the usual way and Patterson projections for the *h*0*l* zones were obtained (Figs. 1 and 2); that for the cadmium compound is probably less accurate because of higher absorption and because fewer terms were used in the synthesis (152 as against 186 for the zinc compound). The large peaks *A* corresponding to the metal–metal vectors were readily identifiable in these projections, and the co-ordinates of one of the chlorine atoms were found by noting that the three peaks *A*, *B*, and *C* were nearly equally spaced in a straight line and were of descending order of magnitude as would be expected for Zn–Zn, $Zn–Cl_I$ and $Cl_I–Cl_I$ vectors. The position of the second chlorine atom could not at first be recognised and it was assumed that the $Zn–Cl_{II}$ peak fell too close to the Zn–Zn peak *A* to be resolved; this was later found to be the case, and in the *h*0*l* Patterson projection for the copper compound (Fig. 3) the resolution is sufficient to separate the peaks so that another equally spaced linear triad *ADE* can be recognised corresponding to the Cu–Cu, $Cu–Cl_{II}$, and $Cl_{II}–Cl_{II}$ vectors.

Assuming that the terpyridyl molecule lay on the side of the zinc atom remote from Cl_I, we were able to show by means of models that the *x* and *z* co-ordinates for Zn (0·12, 0·22) and Cl_I (0·24, 0·14) were compatible with various reasonable arrangements of the molecules in the crystal lattice. We therefore calculated a Fourier synthesis with 63 *h*0*l* terms, allocating signs to the coefficients determined by the zinc and chlorine contributions, and assuming Cl_{II} to have approximately the same (*x*, *z*) co-ordinates as Zn. The map of this synthesis showed Zn and Cl_I in almost the same positions as had been deduced from the Patterson synthesis, but Cl_{II} was clearly resolved with co-ordinates (0·13, 0·35) which thus gave rise in the Patterson synthesis to a $Zn–Cl_{II}$ peak coinciding, not with the Zn–Zn peak *A*, but with the symmetrically related Zn–Zn peak *A*′. With this information it was found possible to account for nearly all the main features of the Patterson syntheses. The (*x*, *z*) co-ordinates of the three heavy atoms were next determined more accurately by means of a Harker $P(x\frac{1}{2}z)$ synthesis of about 800 *hkl* terms and this synthesis also showed a weak $Zn–Cl_I$ peak, indicating that Zn and Cl_I had approximately the same *y* co-ordinates. This result showed that Zn and Cl_I were about 2·3 Å apart and therefore bonded together, and it also showed that the structure could not consist of chains of octahedral complexes since the only way of achieving this would be through linking Cl_{II} atoms along the *b*-axis, and the distance between successive zinc atoms in this direction is much too great for such binding.

In order to carry the analysis further, a comparison of corresponding *h*0*l* intensities for the zinc and cadmium compounds was made and the signs of a few structure factors were determined in this way, but the method was not pursued because (*a*) the high absorption factor (160 $cm.^{-1}$) for the cadmium compound reduced the accuracy of the intensity measurements and (*b*) the Patterson syntheses showed that the assumption that the atomic positions were exactly the same in the two substances was not strictly valid. Attempts to determine signs by means of Harker–Kasper inequalities (*Acta Cryst.*, 1948, **1**, 70) were not successful,

but successive synthesis and recalculation of structure factors enabled us to obtain a *h*0*l* projection of 180 terms in which two of the three pyridine rings were resolved, the third being obscured by the corresponding centrosymmetrically related ring of another molecule (Fig. 4).

The *y* co-ordinates were determined by Patterson three-dimensional line syntheses,

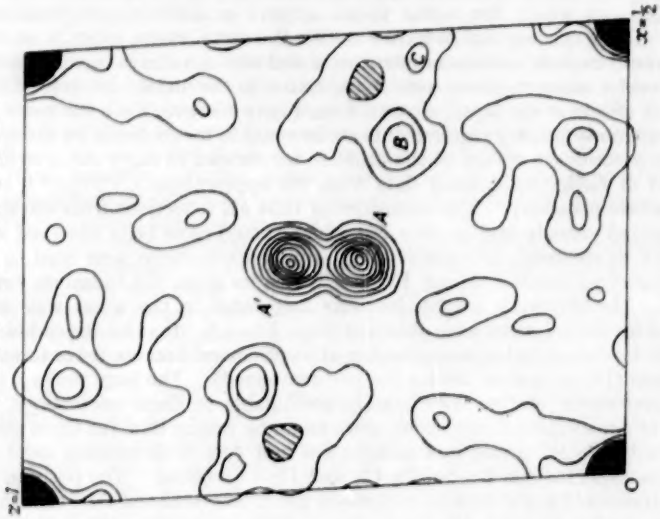


FIG. 2.
$Cd(terpy)Cl_2$; *Patterson h*0*l projection.*

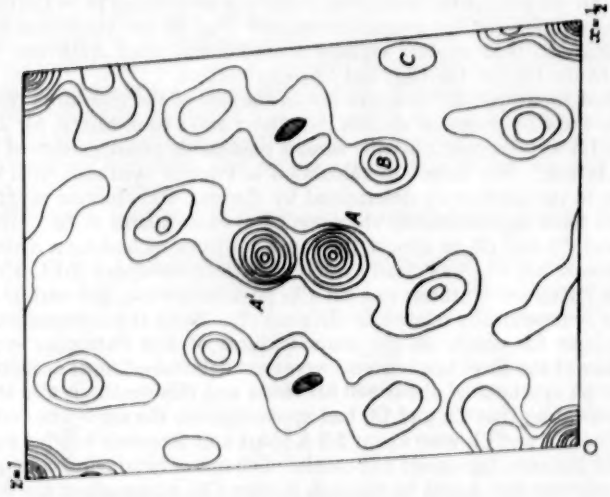


FIG. 1.
$Zn(terpy)Cl_2$; *Patterson h*0*l projection.*

*hk*0 Patterson and Fourier projections, and finally by a section projection (Booth, *Trans. Faraday Soc.*, 1945, **41**, 434) between $z = 0$ and $z = \frac{1}{2}$. At this stage it was clear that the molecule had a somewhat distorted trigonal bipyramidal structure which would not be fully resolved in any projection, and the final co-ordinates were therefore determined by means of a series of three-dimensional Fourier sections and lines. The first stage consisted in determining the signs of about 850 *hkl* structure factors; in many cases these were determined by the contributions of the heavy atoms, but where necessary the contributions

of the carbon and nitrogen atoms were calculated. The electron density was then calculated over seven sections of the unit cell from $y = 1/30$ to $y = 7/30$, the calculation in each section extending from $x = 0$ to $x = 1$ and $z = 0$ to $z = 1$ at intervals of 1/60 in both

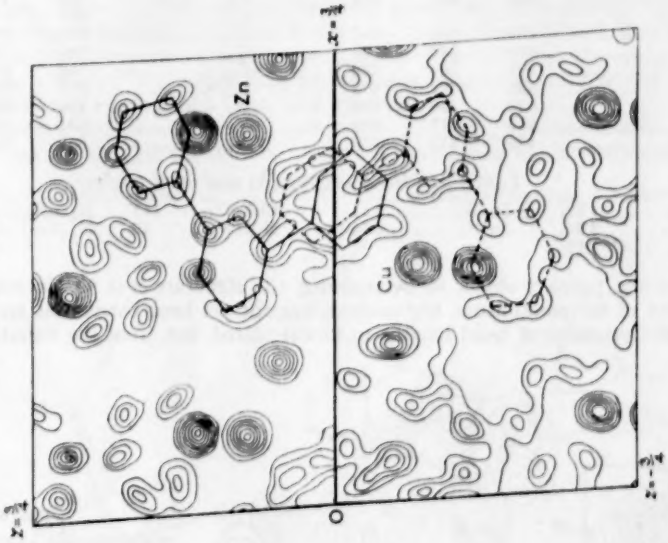


FIG. 4.
Comparision of h0l Fourier projections of Zn(terpy)Cl_2 *and* Cu(terpy)Cl_2

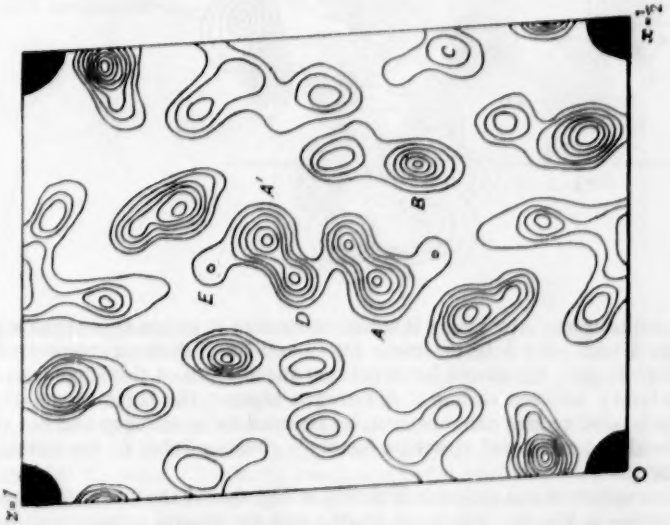


FIG. 3.
Cu(terpy)Cl_2; *Patterson h0l projection.*

directions. The summations were carried out by Hollerith methods (Cox and Jeffrey, *Acta Cryst.*, 1949, **2**, 65; Greenhalgh, *Proc. Leeds Phil. Soc.*, 1950, **5**, 301) and occupied about 12 days. A composite map of the result is shown in Fig. 5. The *y*-co-ordinates were found by calculating the electron densities along lines parallel to the *b*-axis and passing through the maxima in the (*x*, *z*) maps. The results (in thousanths of the cell edges) are given in Table 2, and the bond lengths and bond angles around the zinc atom in Table 3.

TABLE 2. *Atomic co-ordinates in* $ZnCl_2$(terpy).

	x	y	z		x	y	z
Zn	118	097	217	C_8	827	000	261
Cl_I	239	027	135	C_9	858	093	170
Cl_{II}	133	323	334	C_{10}	935	107	155
				C_{11}	971	186	050
C_1	186	844	405	C_{12}	925	263	969
C_2	184	760	523	C_{13}	950	366	874
C_3	108	707	536	C_{14}	033	377	880
C_4	025	767	473	C_{15}	077	293	975
C_5	040	850	386	N_1	124	900	350
C_6	966	917	325	N_2	994	030	236
C_7	889	913	350	N_3	051	203	057

TABLE 3. *Bond lengths* (Å) *and bond angles.*

Zn–Cl_I	2·28$_3$	Zn–N_2	2·11	Cl_IZnCl_{II}...	111°	N_2ZnN_3 ...	72°
Zn–Cl_{II}	2·29$_5$	Zn–N_3	2·34	N_1ZnN_3 ...	79	$N_{1,3}ZnCl$ ...	100 (average)
Zn–N_1	2·19						

Since the primary object in determining the structure was to elucidate the stereochemistry of the metal atom, the analysis has not yet been carried far enough to enable standard deviations of bond lengths to be calculated, but from the variations of the co-

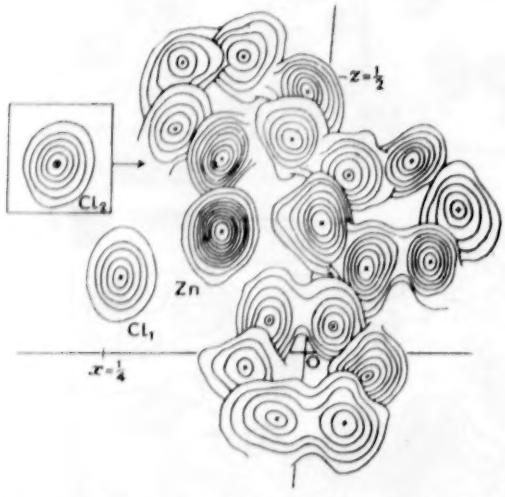


FIG. 5.
Zn(terpy)Cl_2; *composite three-dimensional Fourier diagram.*

ordinates during the later stages it seems reasonable to assign approximate probable errors of ±0·03 Å and ±0·1 Å to the mean Zn–Cl and Zn–N distances respectively, and ±2° to the ClZnCl angle. (It should be noted that the analysis of this stage does not distinguish with certainty between carbon and nitrogen atoms; the three atoms of the terpyridyl molecule bonded to zinc can, however, be assumed to be nitrogen and not carbon.) A list of observed and calculated structure factors is given in Table 4; the reliability factor R is about 25%.

The structure of one molecule is shown in Fig. 6, and the arrangement of the molecules in the lattice in Fig. 7. The bond lengths and the general arrangement of the molecules show quite clearly that the molecule is a five-co-ordinated complex and that there is no possibility of either polymerisation or ionisation (this does not of course exclude the possibility of the Zn–Cl bonds' having some ionic character, although their length, 2·29 Å, is almost exactly what would be expected for covalent bonds). The terpyridyl molecule is flat within experimental error and lies in a plane approximately at right angles to the plane of the Zn–Cl bonds; thus approximately the complex has two planes of symmetry intersecting in a two-fold axis which bisects the ClZnCl angle and the central pyridine ring. The

configuration of the five bonds to the zinc atom is that of a distorted trigonal bipyramid; the two axial bonds are deflected from the ideal position to accommodate the terpyridyl molecule, and the deflection appears to be shared between the zinc and the terpyridyl since, as can be seen from Figs. 5 and 6, neither the two outer N–Zn bonds nor the two pyridine–pyridine bonds are in line with the corresponding ring diameters, all having been deflected inwards. This is understandable, but there seems to be no obvious explanation at present for the significant deviation of the ClZnCl angle from 120°; nevertheless, the configuration is much closer to a trigonal bipyramid than to any other recognised arrangement, and in particular it is certainly not that of a tetragonal pyramid.

The intermolecular distances are normal and do not call for any special comment except to note that neither the zinc nor the chlorine atoms have any atoms in other molecules near

FIG. 6. $Zn(terpy)Cl_2$; *bond lengths and bond angles.*

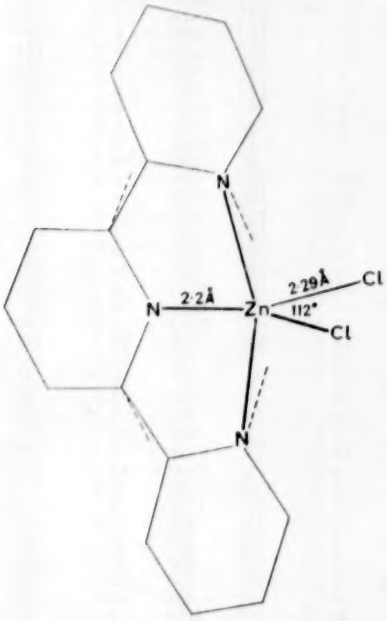
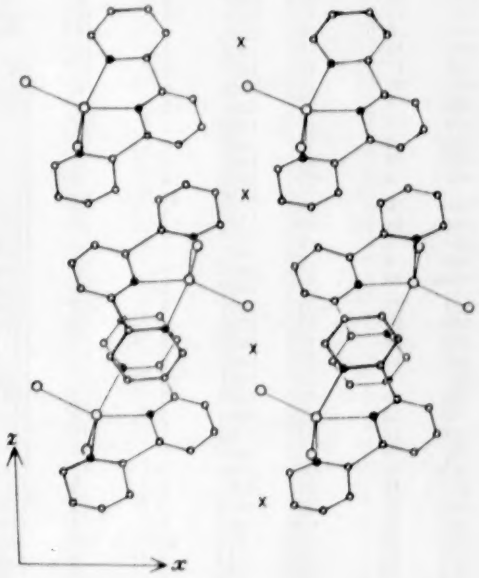


FIG. 7. $Zn(terpy)Cl_2$; *arrangement of molecules in the lattice.*



enough to suggest anything but van der Waals forces between them; the nearest neighbour to zinc is a carbon atom at 4·1 Å and the shortest Cl . . . Cl distance is 5·1 Å. The packing of the molecules is good except along the *a*-axis where there are some gaps the projected positions of which are shown approximately at *X* in Fig. 7.

No detailed analysis has been made of the cadmium compound, but the similarity of the Patterson projection (Fig. 2) to that of the zinc compound (Fig. 1) leaves no doubt that its structure is essentially the same. The same conclusion could be drawn with regard to the copper compound (Fig. 3) but because of its rather different properties (higher solubility, reaction for chloride ion, water of crystallisation), and because the stereochemistry of copper does not normally show much resemblance to that of zinc, we have carried the analysis further. Proceeding in the same way as with the zinc compound, we have made *h*0*l* and *hk*0 Fourier projections; comparison of the *h*0*l* projection with that for the zinc compound at about the same stage of the analysis (Fig. 4) leaves no doubt as to the very close similarity of their structures. The approximate co-ordinates derived from these projections, and the bond distances and angles calculated from them, are only slightly different from the corresponding figures for the zinc compound. The analysis has not yet been

TABLE 4. *Observed and calculated structure factors for* $Zn(terpy)Cl_2$.

Note: These figures are on one-quarter of the absolute scale. Calculations were made with the f values given in the International Tables, with a temperature factor $B = 1{\cdot}0$.

hkl	F (obs.)	F (calc.)	*hkl*	F (obs.)	F (calc.)	*hkl*	F (obs.)	F (calc.)	*hkl*	F (obs.)	F (calc.)
200	22	29	809	14	21	$\bar{6}06$	21	−20	1020	0	−1
400	29	−27	1001	37	−33	$\bar{6}07$	9	−11	1220	7	4
600	14	−9	1002	11	−6	$\bar{6}08$	17	17	1420	5	−3
800	31	27	1003	14	9	$\bar{6}09$	3	11	1620	4	4
1000	8	−6	1004	24	26	$\bar{6}010$	10	−14	1820	4	7
1200	18	−18	1005	16	13	$\bar{8}01$	19	−13	240	13	−11
1400	14	−14	1006	~10	−13	$\bar{8}02$	46	−42	440	28	23
1600	16	16	1007	10	−12	$\bar{8}03$	7	4	640	3	−1
1800	3	1	1008	12	12	$\bar{8}04$	7	4	840	9	−10
2000	7	−8	1009	3	−4	$\bar{8}05$	12	4	1040	6	−2
			1201	7	8	$\bar{8}06$	7	6	1240	19	22
001	8	10	1202	10	11	$\bar{8}07$	14	−12	1440	3	3
002	24	−20	1203	4	6	$\bar{8}08$	0	−2	1640	7	−4
003	15	−10	1204	13	14	$\bar{8}09$	17	22	1840	4	4
004	6	−4	1205	9	−11	$\bar{8}010$	10	−11	260	8	−7
005	11	8	1206	5	−13	$\bar{10}01$	20	14	460	13	14
006	17	12	1207	16	21	$\bar{10}02$	0	0	660	5	4
007	20	17	1208	2	6	$\bar{10}03$	10	−13	860	6	−5
008	3	0	1401	19	17	$\bar{10}04$	8	9	1060	6	−9
009	19	18	1402	5	−2	$\bar{10}05$	4	8	1260	5	8
0010	5	−10	1403	0	1	$\bar{10}06$	0	−4	1460	4	4
0011	14	−20	1404	0	2	$\bar{10}07$	—	−9	280	0	−1
0012	4	−8	1405	4	4	$\bar{10}08$	10	−16	480	5	4
			1406	11	22	$\bar{10}09$	10	10	*110	3	35
020	0	2	1407	5	3	$\bar{10}010$	8	14	310	18	−15
040	14	−12	1408	9	−15	$\bar{12}01$	6	3	510	2	−5
060	7	−6	1601	7	9	$\bar{12}02$	14	14	710	9	5
080	0	2	1602	0	5	$\bar{12}03$	14	−13	910	24	17
0100	10	12	1603	5	−4	$\bar{12}04$	14	−13	1110	8	−6
201	27	−21	1604	9	−8	$\bar{12}05$	—	1	1310	6	−6
202	17	13	1605	6	9	$\bar{12}06$	7	8	1510	5	−6
203	23	23	1606	3	7	$\bar{12}07$	13	16	1710	13	13
204	13	12	1607	8	−13	$\bar{12}08$	2	9	130	13	4
205	1	4	1801	10	−12	$\bar{12}09$	11	−21	330	9	−8
206	26	−22	1802	10	−10	$\bar{12}010$	6	−5	530	2	0
207	12	−9	1803	2	−6	$\bar{14}01$	14	−11	730	7	3
208	18	13	1804	7	11	$\bar{14}02$	9	7	930	9	5
209	5	7	1805	7	10	$\bar{14}03$	16	18	1130	5	−6
2010	14	−15	1806	9	−11	$\bar{14}04$	0	−2	1330	11	11
401	19	15	2001	2	2	$\bar{14}05$	8	−3	1530	0	—
402	23	24	2002	2	−2	$\bar{14}06$	12	−11	1730	0	—
403	13	−4	2003	2	4	$\bar{14}07$	0	4	150	21	−17
404	18	−12	$\bar{2}01$	37	43	$\bar{14}08$	9	6	350	22	19
405	40	−31	$\bar{2}02$	3	2	$\bar{14}09$	0	2	550	30	30
406	18	−10	$\bar{2}03$	0	−1	$\bar{14}010$	6	−11	750	13	−13
407	29	−27	$\bar{2}04$	8	7	$\bar{16}01$	10	−8	950	16	−16
408	11	14	$\bar{2}05$	5	3	$\bar{16}02$	22	−27	1150	4	6
409	17	−17	$\bar{2}06$	24	19	$\bar{16}03$	4	−3	1350	11	11
4010	3	3	$\bar{2}07$	17	−12	$\bar{16}04$	10	11	1550	8	−12
601	13	8	$\bar{2}08$	24	−23	$\bar{16}05$	5	7	1750	4	−5
602	9	−4	$\bar{2}09$	0	−6	$\bar{16}06$	3	−3	170	8	−7
603	26	−16	$\bar{2}010$	12	19	$\bar{16}07$	2	1	370	0	−1
604	13	7	$\bar{4}01$	16	13	$\bar{16}08$	0	−3	570	7	4
605	8	−1	$\bar{4}02$	25	29	$\bar{16}09$	5	9	770	6	−6
606	14	11	$\bar{4}03$	25	−16	1801	12	13	970	4	−3
607	0	0	$\bar{4}04$	20	−20	$\bar{18}02$	3	−7	1170	6	7
608	22	−24	$\bar{4}05$	11	−7	$\bar{18}03$	6	−8	1370	7	9
609	4	−8	$\bar{4}06$	0	−2	$\bar{18}04$	0	10	190	5	7
6010	14	18	$\bar{4}07$	21	23	$\bar{20}01$	7	−1	380	6	−10
801	12	8	$\bar{4}08$	7	9	$\bar{20}02$	8	8	590	7	7
802	18	−12	$\bar{4}09$	~10	−15	$\bar{20}03$	5	−11	210	13	−12
803	13	−14	$\bar{4}010$	5	−9	$\bar{20}04$	8	−10	410	2	−1
804	3	−4	$\bar{6}01$	45	−45				610	28	26
805	11	7	$\bar{6}02$	3	0	220	24	−18	810	8	5
806	10	7	$\bar{6}03$	35	32	420	14	8	1010	18	−15
807	19	−19	$\bar{6}04$	8	5	620	5	−6	1210	3	7
808	0	1	$\bar{6}05$	5	−6	820	22	15	1410	8	6

* This discrepancy is not understood; it may in part be due to extinction.

TABLE 4. (*Continued.*)

hkl	F (obs.)	F (calc.)	*hkl*	F (obs.)	F (calc.)	*hkl*	F (obs.)	F (calc.)	*hkl*	F (obs.)	F (calc.)
1610	0	2	049	12	−10	343	8	−11	$\bar{3}31$	5	5
1810	8	−4	0410	4	−7	344	8	−6	$\bar{3}32$	17	−13
230	20	−20	061	5	−1	211	6	−1	$\bar{3}33$	17	−14
430	0	−4	062	11	7	212	23	23	$\bar{3}34$	12	11
630	10	11	063	10	12	213	13	−6	$\bar{1}21$	7	4
830	8	9	064	12	14	214	5	−3	$\bar{1}22$	51	−49
1030	18	−17	065	13	−11	411	25	24	$\bar{1}23$	9	−6
1230	13	−14	066	0	−2	412	9	−6	$\bar{1}24$	38	28
1430	3	1	067	10	13	413	13	−10	$\bar{3}21$	2	−5
1630	10	11	081	3	3	414	16	−12	$\bar{3}22$	3	−2
250	0	2	082	0	0	221	13	−12	$\bar{3}23$	27	−25
450	0	−1	083	11	−12	222	24	−19	$\bar{3}24$	6	1
650	9	−7	0101	4	5	223	11	9	$\bar{1}41$	12	−13
850	4	4	0102	6	−11	224	22	20	$\bar{1}42$	14	−9
1050	0	—	011	19	−25	225	2	−4	$\bar{1}43$	19	11
1250	0	—	012	15	−7	421	6	2	$\bar{1}44$	16	10
1450	0	—	013	23	16	422	7	5	$\bar{3}41$	11	17
1650	7	11	014	5	6	423	13	8	$\bar{3}42$	12	−10
270	0	1	015	4	−1	424	11	−11	$\bar{3}43$	12	−11
470	2	4	016	9	−6	425	8	−12	$\bar{3}44$	10	11
670	6	−6	017	9	−9	621	10	5	$\bar{2}11$	16	16
870	3	−1	018	14	15	622	0	5	$\bar{2}12$	30	−28
1070	2	5	019	4	3	623	8	5	$\bar{2}13$	22	15
1270	8	16	0110	3	−4	624	5	4	$\bar{2}14$	3	2
290	7	12	031	17	−18	625	15	17	$\bar{4}11$	22	30
490	4	5	032	25	−26	821	23	22	$\bar{4}12$	7	−5
690	5	−4	033	21	20	822	0	2	$\bar{4}13$	15	−9
120	8	−4	034	29	23	823	13	−10	$\bar{4}14$	8	−6
320	7	−5	035	15	−10	241	14	17	$\bar{2}21$	24	−18
520	0	−1	036	12	−13	242	3	6	$\bar{2}22$	3	1
720	23	21	037	0	2	243	5	−4	$\bar{2}23$	2	2
920	0	1	051	6	−5	244	9	−1	$\bar{2}24$	8	−7
1120	12	−10	052	14	−11	441	2	3	$\bar{2}25$	13	13
1320	7	−5	053	4	−5	442	16	−10	$\bar{4}21$	6	2
1520	9	11	054	13	12	443	15	−9	$\bar{4}22$	7	−1
1720	4	9	055	1	2	444	0	−1	$\bar{4}23$	4	−5
140	22	−21	056	0	6	641	18	−22	$\bar{4}24$	13	−12
340	9	−11	057	13	13	642	15	−11	$\bar{4}25$	5	−8
540	10	3	071	—	—	643	8	7	$\bar{6}21$	1	−1
740	15	11	072	8	5	644	13	15	$\bar{6}22$	3	−1
940	13	−11	073	14	−13	841	7	−2	$\bar{6}23$	17	16
1140	12	−10	074	14	−18	842	8	8	$\bar{6}24$	19	20
1340	0	−1	075	10	12	843	2	0	$\bar{6}25$	10	−6
1540	8	7	111	14	−16	844	10	−10	$\bar{8}21$	6	0
160	4	1	112	35	−40	261	6	3	$\bar{8}22$	4	−2
360	9	11	113	10	−7	262	13	14	$\bar{8}23$	14	−10
560	12	−17	114	28	24	263	11	−11	$\bar{8}24$	7	3
760	8	−1	115	17	17	264	11	−8	$\bar{8}25$	9	5
960	0	−2	311	6	−6	461	13	11	$\bar{2}41$	23	−27
1160	7	7	312	19	17	462	13	−8	$\bar{2}42$	9	3
180	6	3	313	24	30	463	14	−11	$\bar{2}43$	21	18
380	11	14	314	13	7	464	0	1	$\bar{2}44$	18	22
580	7	−12	315	25	−28				$\bar{4}41$	1	1
760	0	—	511	6	−5	$\bar{1}11$	15	14	$\bar{4}42$	19	−20
			512	7	7	$\bar{1}12$	14	4	$\bar{4}43$	11	−7
021	12	13	513	7	−4	$\bar{1}13$	3	2	$\bar{4}44$	7	7
022	41	−36	514	11	−11	$\bar{1}14$	10	−5	$\bar{6}41$	6	8
023	22	−19	515	1	0	$\bar{1}15$	21	15	$\bar{6}42$	2	1
024	8	−7	121	20	−23	$\bar{3}11$	12	12	$\bar{6}43$	11	−9
025	9	5	122	39	−26	$\bar{3}12$	5	8	$\bar{6}44$	4	3
026	5	−6	123	25	26	$\bar{3}13$	0	−1	$\bar{8}41$	5	−1
027	6	5	124	3	3	$\bar{3}14$	9	9	$\bar{8}42$	9	8
028	6	10	321	2	2	$\bar{3}15$	14	13	$\bar{8}43$	9	−6
029	5	6	322	18	20	$\bar{5}11$	8	−2	$\bar{8}44$	18	−15
041	8	5	323	10	−7	$\bar{5}12$	7	6	$\bar{2}61$	5	−4
042	18	19	324	34	−31	$\bar{5}13$	14	19	$\bar{2}62$	7	−7
043	0	0	141	15	−14	$\bar{5}14$	8	−1	$\bar{2}63$	12	14
044	11	7	142	17	12	$\bar{5}15$	4	−2	$\bar{2}64$	12	13
045	13	−14	143	10	9	$\bar{1}31$	3	5	$\bar{4}61$	10	8
046	0	0	144	22	16	$\bar{1}32$	5	2	$\bar{4}62$	12	−10
047	12	13	341	21	19	$\bar{1}33$	6	12	$\bar{4}63$	13	−16
048	0	5	342	13	11	$\bar{1}34$	11	5	$\bar{4}64$	8	7

carried far enough to locate the water molecules, which have a comparatively small effect on the intensities, but no evidence has been found contrary to the view that they occupy the cavities *X* (Fig. 7). It is reasonably certain that they cannot in any case be co-ordinated to the copper atom since the disposition of the two chlorine atoms and the terpyridyl molecule in a trigonal bipyramid around the central atom would prevent the water from coming closer than $3\frac{1}{2}$—4 Å to the latter. It is proposed to make a more detailed analysis to determine the bond lengths accurately, and in the course of this work it is hoped to locate the water molecules with certainty.

The trigonal bipyramidal arrangement of dsp^3 bonds was predicted by Kimball (*J. Chem. Phys.*, **1940**, **8**, 188) and is known to occur in a small number of compounds, but this appears to be the first example of this configuration for zinc, copper, or cadmium or involving a chelate group. On the other hand Daudel and Bucher (*J. Chim. phys.*, **1945**, **42**, 6) have suggested that when the *d* orbitals involved in hybridisation have a lower principal quantum number than the *s* and *p* orbitals (as in Ni^{II} and perhaps Cu^{II}) the configuration should be that of a tetragonal pyramid (with the central atom in the plane of the base and not above it as suggested by Kimball for d^2sp^2 hybridisation), and Jensen and Nygaard (*Acta Chem. Scand.*, **1949**, **3**, 474) have shown that the compound $NiBr_2,2PEt_3$ almost certainly has this configuration. In our case it is to be expected that the zinc orbitals involved in binding will all be in the fourth quantum group, so that the conditions postulated by Daudel and Bucher do not apply and our results are in agreement with Kimball's theory. The case of the cadmium compound is precisely analogous.

It should be possible for cupric complexes to exist with the tetragonal pyramidal configuration corresponding to $3d4s4p^3$ hybridisation (although the fifth bond might be weak) and there is some evidence for the existence of the ion $[Cu(en)_2NH_3)]^{++}$ which might be expected to have this structure. If, however, Daudel and Bucher's theory is accepted, our finding that $Cu(terpy)Cl_2$ is trigonal bipyramidal indicates that the hybridisation in this case is $4d4s4p^3$. The nature of the ligands no doubt has considerable influence, but it cannot be argued that the terpyridyl molecule has a " straight-jacket " effect since three bonds suitably disposed to co-ordinate with the three nitrogen atoms are available equally with either a trigonal or a tetragonal configuration of the central atom. It is possible that the energy difference between the two configurations is in many cases not very great, and precise identification of the factors which determine the configuration actually adopted in various circumstances can therefore probably not be made on the data available at present.

A detailed account of the stucture of terpyridylcopper chloride and also an account of the crystallography of a number of other polypyridyl complexes will be published later.

Experimental

The zinc and cadmium compounds were supplied by the late Sir Gilbert Morgan and (the late) Dr. F. H. Burstall. The copper compound was prepared by Morgan and Burstall's method (*loc. cit.*).

Terpyridylzinc chloride was obtained from aqueous solutions in two crystalline forms, both monoclinic and both pale greenish-yellow, which were readily interconvertible by crystallisation. Crystals of form I were acicular combinations of {110} and {011} elongated parallel to [*c*] and those of form II were prismatic combinations of {110}, {100}, {001} and {20$\bar{1}$} also elongated parallel to [*c*]. Both forms were diamagnetic and did not show pyroelectricity when tested in liquid air.

Terpyridylcadmium chloride had a darker colour than the zinc compound, and had a higher density (Table 1) but otherwise resembled it closely in every respect.

Terpyridylcupric chloride dihydrate was obtained as bluish-green prisms which were very similar to form II of the zinc and the cadmium compound. Recrystallisation did not yield any other type of crystal. The crystals were paramagnetic.

Terpyridylzinc bromide and iodide were only very slightly soluble. A few small needles of form I were obtained by slow evaporation of aqueous solutions over a period of many weeks. No crystals of form II were obtained.

All *X*-ray photographs were taken with copper K_α radiation. The cell dimensions were determined by means of rotation and Weissenberg photographs and the intensity measurements were made by visual estimation on Weissenberg photographs. Three films were used for each

photograph, which was taken twice with exposures of 4 hr. and 32 hr. so that a set of six films was obtained for each crystal setting, covering a wide range of intensities. Developing, fixing, and washing of the films was done under controlled conditions. Visual estimation of the intensities was controlled by sets of calibration spots obtained from the actual crystals being examined. No corrections for absorption of *X*-rays in the crystal were made ($\mu = 56$ cm.$^{-1}$ for the zinc compound) but errors were minimised by using equant crystals of appropriate size (about 0·3 mm.). The intensities were measured on an arbitrary scale, and the structure amplitudes calculated from them in the usual way and at a later stage put on the proper scale by comparison with calculated structure amplitudes.

We express our gratitude to (the late) Dr. F. H. Burstall for gifts of material, to (the late) Dr. J. S. Jennings and Mr. A. J. Shorter, who made some preliminary measurements in 1938—1939, and to Mr. D. M. S. Greenhalgh and Miss B. Long for assistance with the calculations. We acknowledge a D.S.I.R. maintenance award and a Senior Ellison Fellowship held by one of us (D. E. C. C.) and the provision of apparatus by the Royal Society and Imperial Chemical Industries Limited.

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120. *The Constituents of High-boiling Petroleum Distillates. Part III.* Anthracene Homologues in a Kuwait Oil.*

By W. Carruthers.

2 : 6- and 2 : 7-Dimethyl-, 2 : 3 : 6-trimethyl-, and 1 : 3 : 5 : 7-, 1 : 3 : 6 : 7-, and 2 : 3 : 6 : 7-tetramethyl-anthracene and four unidentified anthracene homologues have been isolated from fractions of a Kuwait mineral oil by reaction with maleic anhydride.

Very few polycyclic aromatic hydrocarbons have been detected in mineral-oil fractions. Gavat and Irimescu [1] found naphthalene homologues and phenanthrene in a Roumanian oil, and recently Moore, Thorpe, and Mahoney [2] encountered 3-methylchrysene in an American crude oil. A second chrysene derivative and perylene were found in another American crude by Carruthers and Cook,[3] while Carruthers and Douglas [4] described the isolation of three trimethylnaphthalenes from a Trinidad oil. The anthracene derivatives named in the summary have now been isolated from fractions of a Kuwait (Middle East) oil by reaction with maleic anhydride.

The sixteen 2½°-fractions employed, covering the boiling range 350—390°, were prepared in the Chemical Engineering Laboratories of the University of Birmingham by fractional distillation of the crude oil under reduced pressure and extraction of the distillates with aqueous acetone. The author is very much indebted to Professor F. Morton for carrying out these operations and supplying the resultant material for this investigation. The aromatic-enriched extracts were treated with maleic anhydride at 100°, giving small yields of alkali-soluble adducts, whose decomposition by distillation from sodium hydroxide afforded viscous oils with well-marked anthracene-type ultraviolet absorption spectra. Anthracenes crystallised from some of these oils and others were obtained by chromatography of the oils on alumina. The Table summarises the results obtained.

The well-known [5,6,7] eutectic mixture, m. p. 225—226°, of 2 : 6- and 2 : 7-dimethylanthracene separated from some of the earlier fractions. On oxidation it afforded 2 : 6- and 2 : 7-dimethylanthraquinone, identified by comparison with authentic specimens.

* Part II, *J.*, 1955, 1847.

[1] Gavat and Irimescu, *Ber.*, 1941, **74**, 1812; 1942, **75**, 820.
[2] Moore, Thorpe, and Mahoney, *J. Amer. Chem. Soc.*, 1953, **75**, 2259.
[3] Carruthers and Cook, *J.*, 1954, 2047.
[4] Carruthers and Douglas, *J.*, 1955, 1847.
[5] Lavaux, *Compt. rend.*, 1911, **152**, 1400, and earlier references; *Ann. Chim.*, 1910, **20**, 433; **21**, 131.
[6] Hey, *J.*, 1935, 72.
[7] Morgan and Coulson, *J.*, 1929, 2203.

Chromatography of the remaining oil from fraction 3 gave 2 : 6-dimethylanthracene. In a similar manner, 2 : 7-dimethylanthracene was obtained from fraction 4.

Several of the intermediate fractions, on being cooled, deposited 2 : 3 : 6-trimethylanthracene, which was identified by mixed m. p. and by oxidation to 2 : 3 : 6-trimethylanthraquinone.[8]

2 : 3 : 6 : 7-Tetramethylanthracene separated from the two highest-boiling fractions, and was likewise identified by mixed m. p. and by oxidation to the quinone. By chromatography of the remaining oil from these fractions the previously unknown 1 : 3 : 6 : 7-tetramethylanthracene was obtained. It was identified by comparison of its quinone with the synthetic compound,[10] and by preparation of the hydrocarbon itself by Elbs pyrolysis of 2 : 4 : 6 : 3′ : 4′-pentamethylbenzophenone. A third tetramethylanthracene, isolated

from fractions 13 and 14 by chromatography, is regarded as 1 : 3 : 5 : 7-tetramethylanthracene because of the close agreement of the melting points of the hydrocarbons and of the quinones with those recorded in the literature,[11] although direct comparison has not been possible.

Chromatography of the oily portions of fractions 10 and 12 afforded small amounts of three other hydrocarbons, $C_{17}H_{16}$ or $C_{18}H_{18}$ (see Table). The anthracenic structure of these compounds was shown by their ultraviolet absorption spectra, but their m. p.s and those of the corresponding quinones do not correspond with those recorded for any C_{17} or C_{18} anthracene or its quinone, and the compounds have not been identified.

Fraction	Yield *	B. p.†	Products
1	0·9	350—352·5°	Eutectic mixture of 2 : 6- and 2 : 7-dimethylanthracene
2	0·9	352·5—355	" " "
3	0·8	355—357·5	Eutectic mixture and 2 : 6-dimethylanthracene
4	0·5	357·5—360	2 : 7-Dimethylanthracene
5	0·9	360—362·5	2 : 3 : 6-Trimethylanthracene
6	1·6	362·5—365	—
7	0·9	365—367·5	2 : 3 : 6-Trimethylanthracene
8	1·0	367·5—370	"
9	0·9	370—372·5	—
10	0·5	372·5—375	2 : 3 : 6-Trimethylanthracene; hydrocarbon, m. p. 108—110°; hydrocarbon, m. p. 224—225°
11	0·8	375—377·5	2 : 3 : 6-Trimethylanthracene
12	0·9	377·5—380	2 : 3 : 6-Trimethylanthracene; hydrocarbon, m. p. 224—225°; hydrocarbon, m. p. 169—170
13	1·0	380—382·5	1 : 3 : 5 : 7-Tetramethylanthracene
14	1·1	382·5—385	"
15	0·9	385—387·5	1 : 3 : 6 : 7- and 2 : 3 : 6 : 7-Tetramethylanthracene
16	1·4	387·5—390	"

* Yield of maleic anhydride extract, as percentage of distillate fraction.

† These are the equivalent b. p.s at atmospheric pressure of the original distillates. The actual distillations were carried out under reduced pressures.

An unknown tetramethylanthracene, m. p. 67—69°, was obtained from the combined fractions 14 and 15 by crystallisation of molecular complexes. The large bathochromic shift of 13—15 mμ in the ultraviolet absorption spectrum of this compound suggests the presence of a substituent in one of the *meso*-positions.[12]

Experimental

Melting points were determined on a Kofler hot stage. Ultraviolet absorption spectra were measured in 95% ethanol on a " Unicam " spectrophotometer.

[8] Morgan and Coulson, *J.*, 1929, 2551.

[9] *Idem*, *J.*, 1931, 2323; Barnett, Goodway, and Watson, *Ber.*, 1933, **66**, 1876; Hey, ref. 6; *J.*, 1938, 1847.

[10] Fieser, *J. Amer. Chem. Soc.*, 1935, **57**, 1679.

[11] Seer, *Monatsh.*, 1912, **33**, 33; Scholl, Meyer, and Keller, *Annalen*, 1934, **513**, 295.

[12] Friedel and Orchin, " Ultraviolet Spectra of Aromatic Compounds," John Wiley and Sons, Inc., New York, 1951.

Reaction with Maleic Anhydride.—The starting materials were dark thick oils at ordinary temperatures. A Kuwait (Middle East) oil was first roughly distilled under reduced pressure, and a fraction boiling above 340° carefully refractionated by using a Stedman type column at 2—3 cm. pressure. Fractions were taken every 2½° and distillation was discontinued when there was evidence of cracking (b. p. 390°). Aromatic extracts were prepared from the distillates in approximately 20% yield by treatment with 5% aqueous acetone in a counter-current spinning-disc solvent-extraction unit.

In a typical experiment, the extract, after being washed with dilute hydrochloric acid and sodium hydroxide, was stirred at 100° with maleic anhydride (1/10 part) for 5—6 hr. A slight excess of sodium hydroxide solution (20%) was cautiously added to the cooled mixture, and the whole stirred at 60° for some time. The sodium salt of the adduct often separated as a dark tar at the interface of the two layers, and was carefully separated, along with the aqueous solution, and dissolved in warm water. The oil was washed several times with warm water and the combined aqueous solutions thoroughly extracted with benzene and acidified. The gummy adduct was taken up in benzene, washed with water, recovered, and decomposed by distillation from sodium hydroxide, affording, generally, an orange-red viscous oil at 180—200°/0·2 mm.

Eutectic Mixture of **2 : 6-** *and* **2 : 7-***Dimethylanthracene.*—A solution of the adduct-forming material (2·6 g.) from fraction **1** in light petroleum (b. p. 60—80°) deposited crystals at −10°. After chromatography on alumina in light petroleum (b. p. 60—80°) and crystallisation from ethanol–benzene, the eutectic mixture was obtained as plates (25 mg.), m. p. 225—227° (Found : C, 93·2; H, 6·9. Calc. for $C_{16}H_{14}$: C, 93·2; H, 6·8%). More of this substance was isolated in the same way from the two succeeding fractions, and by chromatography of the remaining oily part of the present fraction.

Oxidation of the hydrocarbon with chromic acid in acetic acid, and chromatography of the crude product on alumina in benzene afforded yellow crystals, m. p. 225—237°. Repeated crystallisation from benzene–ethanol yielded **2 : 6**-dimethylanthraquinone, m. p. and mixed m. p. 241—242° (Found : C, 81·5; H, 5·2. Calc. for $C_{16}H_{12}O_2$: C, 81·3; H, 5·1%). The mother liquors afforded a small amount of pale yellow crystals, m. p. 176—180°; when mixed with **2 : 7**-dimethylanthraquinone of m. p. 168—169° the m. p. was 170—175°. (This experiment was carried out by Mr. A. G. Douglas, B.Sc.)

2 : 6-*Dimethylanthracene.*—After removal of a small amount of eutectic mixture, the oily adduct-forming material from fraction **3** (3·0 g.) was chromatographed on alumina (140 g.), light petroleum (b. p. 40—60°; later b. p. 60—80°), mixtures of the latter and benzene, and finally benzene being used as eluants. Several of the fractions obtained gave crystals at −10° from some of which **2 : 6**-dimethylanthracene was obtained by further chromatography and crystallisation from benzene as nearly colourless blades, m. p. 237—240° (lit., 250° corr.). Oxidation with chromic acid afforded **2 : 6**-dimethylanthraquinone as pale yellow needles, m. p. 235° (from ethanol–benzene) not depressed when mixed with an authentic specimen (m. p. 239—240°).

2 : 7-*Dimethylanthracene.*—A solution of the " anthracene fraction " from distillate **4** (3·8 g.), in light petroleum (b. p. 40—60°) was chilled to −70°, and the solid which separated (100 mg.) crystallised from benzene–ethanol. **2 : 7**-Dimethylanthracene was obtained as nearly colourless blades, m. p. 235° alone or mixed with an authentic specimen (Found : C, 93·2; H, 6·8%). Light absorption : $\lambda_{max.}$ 256·5 (infl. 327), 343, 360, 379·5 mμ [log ε 5·22, (3·23), 3·62, 3·72, 3·60]. Oxidation with chromic acid afforded **2 : 7**-dimethylanthraquinone as pale yellow needles (from methanol), m. p. and mixed m. p. 163—165°.

2 : 3 : 6-*Trimethylanthracene.*—This hydrocarbon separated from several of the intermediate anthracene fractions (see Table) when their solutions in light petroleum (b. p. 40—60°) were kept at −10°. After purification by chromatography on alumina, it crystallised from benzene–ethanol in nearly colourless blades (50 mg.), m. p. 244—245° (Found : C, 93·0; H, 7·1. Calc. for $C_{17}H_{16}$: C, 92·7; H, 7·3%). Light absorption : $\lambda_{max.}$ 258, (infl. 313), (infl. 325), 342·5, 359·5, 380 mμ [log ε 5·34, (3·18), (3·44), 3·65, 3·77, 3·68]. The m. p. of a mixture with an authentic specimen (m. p. 252—253°) was 245—246°. The quinone formed pale yellow needles (from ethanol–benzene), m. p. 236—237° alone or mixed with **2 : 3 : 6**-trimethylanthraquinone.

1 : 3 : 5 : 7-*Tetramethylanthracene.*—This was obtained by chromatography of fractions **13** and **14** by the general method outlined above. The crude material (100 mg.) was purified by chromatography and crystallisation from ethanol–benzene, and gave the pure hydrocarbon as needles, m. p. 164—165° (20 mg.) (lit., m. p. 163—164°) (Found : C, 92·2; H, 7·4. Calc. for $C_{18}H_{18}$: C, 92·3; H, 7·7%). Light absorption : $\lambda_{max.}$ 253, 261, (infl. 320), (infl. 330), 339, 353, 368, 387 mμ [log ε 4·95, 5·29, (3·33), (3·46), 3·58, 3·70, 3·73, 3·73]. The quinone was obtained

from benzene–ethanol as yellow needles, m. p. 238—239° (lit., m. p. 237°) (Found : C, 81·8; H, 5·9. Calc. for $C_{18}H_{16}O_2$: C, 81·8; H, 6·1%). The picrate formed dark purple needles (from ethanol–benzene), m. p. 189—190° (lit., m. p. 189—190°).

1 : 3 : 6 : 7- *and* 2 : 3 : 6 : 7-*Tetramethylanthracene*.—Light petroleum (b. p. 60—80°) solutions of fractions 15 and 16 deposited small amounts of a yellow substance at −10°. This was purified by chromatography on alumina and crystallisation from ethanol–benzene, affording 2 : 3 : 6 : 7-tetramethylanthracene as fluffy yellow needles (6 mg.), m. p. 292—293° alone or mixed with an authentic specimen (Found : C, 92·5; H, 7·7%). Light absorption : $\lambda_{max.}$ (in *cyclo*hexane) 252, 261, 275·5, 294, (infl. 314), 328, 343, 360, 380 mμ [log ε 4·87, 5·37, 4·17, 3·16, (3·16), 3·45, 3·65, 3·78, 3·68]. (The maxima at 275·5 and 294 are spurious and indicate the presence of some persistent impurity.) Oxidation of the hydrocarbon with chromic acid afforded 2 : 3 : 6 : 7-tetramethylanthraquinone as nearly colourless needles, m. p. 317—320° (from benzene) not depressed when mixed with authentic material.

Chromatography on alumina of the remaining oils of fractions 15 and 16 produced crystalline fractions from which by further chromatography and crystallisation from benzene–ethanol 1 : 3 : 6 : 7-*tetramethylanthracene* was obtained as pale yellow plates, m. p. 131—132° (Found : C, 92·3; H, 7·7. $C_{18}H_{18}$ requires C, 92·3; H, 7·7%). Light absorption : $\lambda_{max.}$ 253, 261, (infl. 330), 344, 362, 383 mμ [log ε 4·99, 5·30, (3·51), 3·69, 3·81, 3·71]. Oxidation with chromic acid gave 1 : 3 : 6 : 7-tetramethylanthraquinone as pale yellow needles, m. p. and mixed m. p. 198—199° (Found : C, 81·8; H, 6·3. Calc. for $C_{18}H_{16}O_2$: C, 81·8; H, 6·1%).

Unidentified Anthracene Homologues.—Chromatography on alumina (350 g.) of the anthracene fraction 10 (5·0 g.) by the general method outlined above yielded three products. (i) 2 : 3 : 6-Trimethylanthracene, m. p. 248—250°, was identified by mixed m. p. (ii) A *substance* which, after further chromatography and crystallisation from methanol–benzene, formed blades (10 mg.), m. p. 108—110° (Found : C, 92·2; H, 7·5. $C_{17}H_{16}$ requires C, 92·7; H, 7·3. $C_{18}H_{18}$ requires C, 92·3; H, 7·7%). Light absorption : $\lambda_{max.}$ 258, (infl. 317), 329, 344, 361, 381 mμ [log ε 5·03, (3·17), 3·43, 3·66, 3·81, 3·73]. Its *quinone* crystallised from benzene–ethanol in pale yellow needles, m. p. 193—194° (Found : C, 81·9; H, 5·9. $C_{17}H_{14}O_2$ requires C, 81·6; H, 5·6. $C_{18}H_{16}O_2$ requires C, 81·8; H, 6·1%). The m. p. was depressed when the compound was mixed with 1 : 2 : 3-trimethylanthraquinone (m. p. 187—188°), prepared as described by Baddeley, Holt, and Makar.[13] (iii) The third hydrocarbon formed pale yellow blades, m. p. 224—225° (10 mg.), from ethanol–benzene (Found : C, 92·5; H, 7·4%). Light absorption : $\lambda_{max.}$ 258, 331, 347, 367, (infl. 381), 386 mμ [log ε 5·08, 3·49, 3·80, 4·04, (3·81), 3·90]. Its quinone separated from ethanol–benzene in fine yellow needles, m. p. 225—226°, and depressed the m. p. of the hydrocarbon.

The hydrocarbon, m. p. 224—225°, was also obtained by chromatography of fraction 12, and accompanied another substance which, after further chromatography, gave blades, m. p. 169—170°, from ethanol–benzene (30 mg.) (Found : C, 92·5; H, 7·4%). Light absorption : $\lambda_{max.}$ 260, 333, 348·5, 366, 385 mμ [log ε 5·17, 3·40, 3·63, 3·74, 3·62]. Oxidation with chromic acid afforded a quinone as pale yellow needles, m. p. 169—170° (Found : C, 81·7; H, 5·6%); reduction of the quinone with zinc and acetic acid regenerated the hydrocarbon, thus showing the absence of *meso*-substituents.

Attempts to obtain crystalline hydrocarbons from some of the gummy chromatogram fractions by codistillation with ethylene glycol, as described by Farthing,[14] were unsuccessful.

Crystallisation of Molecular Complexes.—The benzene and light petroleum–benzene eluates of fractions 14 and 15 were combined, and the oil (5·6 g.) treated with picric acid (6 g.) in ethanol. The dark purple picrate was crystallised three times from benzene–ethanol, decomposed on alumina, and the recovered oil converted into its *s*-trinitrobenzene complex. After repeated crystallisation from benzene, the red needles (m. p. about 159°) were decomposed with stannous chloride in acetic acid. The recovered oil was chromatographed on alumina in light petroleum (b. p. 60—80°) and afforded a pale yellow oil (100 mg.) which crystallised at −10°. Crystallisation from methanol gave pale yellow blades, m. p. 67—69° (Found : C, 92·4; H, 7·4. $C_{18}H_{18}$ requires C, 92·3; H, 7·7%). Light absorption : $\lambda_{max.}$ 253, 261, (infl. 335), 352, 370, 390 mμ [log ε 4·91, 5·23, (3·44), 3·70, 3·83, 3·77]. The *s-trinitrobenzene complex* formed bright red needles, m. p. 167—168°, from methanol–benzene (Found : C, 64·7; H, 4·9. $C_{18}H_{18},C_6H_3O_6N_3$ requires C, 64·4; H, 4·7%). The picrate crystallised from ethanol in brown needles, m. p. 157—159°.

2 : 4 : 6 : 3′ : 4′-*Pentamethylbenzophenone*.—A solution of aluminium chloride (30 g.) and 3 : 4-dimethylbenzoyl chloride (36·5 g.) in methylene chloride (200 c.c.) was added to one of

[13] Baddeley, Holt, and Makar, *J.*, 1952, 2415.
[14] Farthing, *J.*, 1953, 3261.

mesitylene (26 g.) in methylene chloride (200 c.c.), cooled in ice water. After ½ hr. at room temperature the orange-red solution was poured on ice, and the methylene chloride layer washed (sodium hydroxide solution and water), dried, and evaporated. The *ketone* was crystallised from light petroleum (b. p. 40—60°) and from methanol, and formed rhombs, m. p. 86—87° (32 g.) (Found : C, 85·7; H, 7·9. $C_{18}H_{20}O$ requires C, 85·7; H, 8·0%).

Elbs Pyrolysis.—The ketone (5·0 g.) was heated at 340° in a metal-bath for 8 hr. The dark semi-solid product was chromatographed on alumina in benzene–light petroleum (b. p. 60—80°) (1 : 4). This removed most of the colour, and afforded a yellow gum (2·7 g.) and, later, a solid (0·5 g.). The latter crystallised from benzene in plates, m. p. 250—252° alone or mixed with 2 : 3 : 6-trimethylanthracene (Found : C, 93·0; H, 7·0. Calc. for $C_{17}H_{16}$: C, 92·7; H, 7·3%). The oil solidified and after several crystallisations from ethanol formed needles, m. p. 129—130° (400 mg.). This material was further purified by oxidation to the quinone (m. p. and mixed m. p. with 1 : 3 : 6 : 7-tetramethylanthraquinone, 196—197°), and reduction of the latter by the two-stage method of Badger and Cook.[15] 1 : 3 : 6 : 7-*Tetramethylanthracene* was obtained as prismatic needles (120 mg.), m. p. 130° (from benzene–ethanol) (Found : C, 92·1; H, 7·6. $C_{18}H_{18}$ requires C, 92·3; H, 7·7%). Light absorption : $\lambda_{max.}$ 251, 260, (infl. 330), 345, 362, 383 mμ [log ε 4·98, 5·33, (3·42), 3·66, 3·76, 3·65]. The m. p. of a mixture with the hydrocarbon from the oil was 130—131°.

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UNIVERSITY OF GLASGOW. [*Received, September 5th,* 1955.]

[15] Badger and Cook, *J.*, 1939, 802.

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121. *Solutions in Sulphuric Acid. Part XVIII.* A Conductometric Investigation of the Ionisation of some Carboxylic Acid Anhydrides.*

By R. FLOWERS, R. J. GILLESPIE, and S. WASIF.

The electrical conductivities of dilute solutions of acetic, benzoic, succinic, and phthalic anhydrides in sulphuric acid, and of acetic and benzoic acids in dilute oleum, have been investigated. The results have been correlated with Leisten's recent cryoscopic measurements,[1] some older cryoscopic work, and the results of our own new measurements of the freezing-point depression produced by phthalic anhydride in sulphuric acid. Our results support Leisten's conclusion that acetic and benzoic anhydrides ionise completely according to equation (1) and also show that succinic and phthalic anhydrides are incompletely ionised.

LEISTEN [1] has recently concluded, from cryoscopic measurements, that acetic anhydride and benzoic anhydride ionise in sulphuric acid according to equation (1)

$$(R{\cdot}CO)_2O + 3H_2SO_4 = 2R{\cdot}CO_2H_2^+ + HS_2O_7^- + HSO_4^- \quad . \quad . \quad . \quad . \quad (1)$$

$$(R{\cdot}CO)_2O + 2H_2SO_4 = R{\cdot}CO^+ + R{\cdot}CO_2H_2^- + 2HSO_4^- \quad . \quad . \quad . \quad . \quad (2)$$

to form the corresponding carboxylic acidium ions and not according to equation (2) to form a carboxylic acidium ion and an acyl ion as previously suggested by Gillespie.[2]

This paper presents the results of conductivity measurements on solutions of acetic, benzoic, succinic, and phthalic anhydrides in 100% sulphuric acid and of acetic and benzoic acids in oleum. These results support Leisten's conclusion that acetic and benzoic anhydrides ionise according to equation (1) by removing water from the solvent to form acidium ions and that acyl ions are not formed in detectable amounts. Our results also

* Part XVII, *J.*, 1956, 80.

[1] Leisten, *J.*, 1955, 298.

[2] Part VIII, Gillespie, *J.*, 1950, 2997.

show that the ionisation of succinic and phthalic anhydrides, whose nature has not yet been clearly established, is incomplete.

Specific conductances of solutions of the anhydrides in 100% sulphuric acid are given in Table 1.

TABLE 1. *Specific conductances of acetic, benzoic, succinic, and phthalic anhydride solutions at 25°.*

Acetic anhydride		Acetic anhydride		Benzoic anhydride		Benzoic anhydride	
c (M)	100κ	c (M)	100κ	c (M)	100κ	c (M)	100κ
0·0000	1·043	0·0000	1·043	0·0000	1·043	0·0000	1·043
0·0229	1·125	0·0108	1·062	0·0236	1·117	0·0090	1·058
0·0391	1·242	0·0384	1·195	0·0388	1·216	0·0407	1·233
0·0570	1·386	0·0669	1·421	0·0684	1·456	0·0561	1·354
0·0757	1·559	0·0884	1·624	0·0912	1·645	0·0824	1·571
0·0931	1·693	0·1114	1·818	0·1330	1·974	0·1070	1·771
0·1160	1·888	0·1401	2·055	0·1701	2·238		
0·1390	2·074	0·1703	2·288	0·2229	2·560		
Succinic anhydride		Succinic anhydride		Phthalic anhydride		Phthalic anhydride	
c (M)	100κ	c (M)	100κ	c (M)	100κ	c (M)	100κ
0·0000	1·043	0·0000	1·043	0·0000	1·043	0·0000	1·043
0·0122	1·067	0·0314	1·151	0·0124	1·046	0·0112	1·044
0·0438	1·188	0·0763	1·352	0·0465	1·057	0·0462	1·052
0·0694	1·297	0·1036	1·463	0·0979	1·080	0·0922	1·070
0·1051	1·441	0·1557	1·647	0·1619	1·114	0·1382	1·091
0·1498	1·598	0·2205	1·837	0·2266	1·150	0·2231	1·136
0·2194	1·803	0·2963	2·020	0·2936	1·188	0·3090	1·182
0·2762	1·944			0·3892	1·240	0·3929	1·226

The specific conductances of acetic anhydride solutions are compared with those of acetic acid [which exists as the mono(hydrogen sulphate)] and potassium sulphate [which exists as the di(hydrogen sulphate)] in Fig. 1, and the specific conductances of solutions of benzoic anhydride are compared with those of benzoic acid and potassium sulphate in Fig. 2. In Fig. 3 the specific conductances of solutions of succinic anhydride and phthalic anhydride are compared with those of the strong electrolyte acetic acid, the weak electrolytes *p*-nitrotoluene and dichloroacetic acid, and the non-electrolyte sulphuryl chloride. The molar conductances of all four anhydrides are compared with those of nitric acid and potassium sulphate [existing as their di(hydrogen sulphates)] and acetic acid and benzoic acid [existing as their mono(hydrogen sulphates)] in Table 2. The conductivities of the comparison electrolytes given in Figs. 1—3 and Table 2 have been taken from Part XII [3] and from some additional new measurements at the lower concentrations.

TABLE 2. *Comparison of the molar conductances of acetic, benzoic, succinic, and phthalic anhydrides with some other electrolytes.*

	Molarity				Molarity		
Electrolyte	0·05	0·10	0·15	Electrolyte	0·05	0·10	0·15
Nitric acid $\{(NO_2^+)(H_3O^+)(HSO_4^-)_2\}$	306	229	197	Acetic acid $\{(CH_3{\cdot}CO_2H_2^+)(HSO_4^-)\}$	244	156	129
Potassium sulphate $\{(K^+)_2(HSO_4^-)_2\}$	312	238	204	Benzoic acid $\{(Ph{\cdot}CO_2H_2^+)(HSO_4^-)\}$	246	158	130
Acetic anhydride	258	172	143	Succinic anhydride	244	142	107
Benzoic anhydride	260	173	140	Phthalic anhydride	212	108	74

Conductivities of Acetic and Benzoic Anhydrides in Sulphuric Acid.—The conductivities of solutions of acetic and benzoic anhydrides are much closer to those of solutions of a mono(hydrogen sulphate) than a di(hydrogen sulphate). They are therefore consistent with ionisation according to equation (1) and not equation (2). That the conductivities are actually a little greater than for a mono(hydrogen sulphate) is to be expected for ionisation according to equation (1), since the hydrogen disulphate ion that is formed will undergo a small amount of solvolysis [4] according to equation (3) and hence the hydrogen

$$HS_2O_7^- + H_2SO_4 = H_2S_2O_7 + HSO_4^- \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

[3] Part XII, Gillespie and Wasif, *J.*, 1953, 221.
[4] Part IV, Gillespie, *J.*, 1950, 2516.

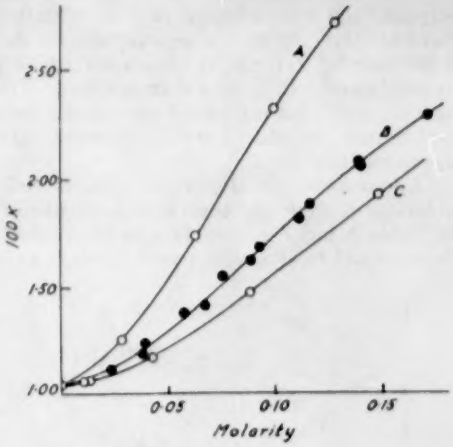


FIG. 1. *Comparison of the specific conductances of acetic anhydride and other electrolytes.*

A, K_2SO_4
B, $(CH_3{\cdot}CO)_2O$
C, $CH_3{\cdot}CO_2H$

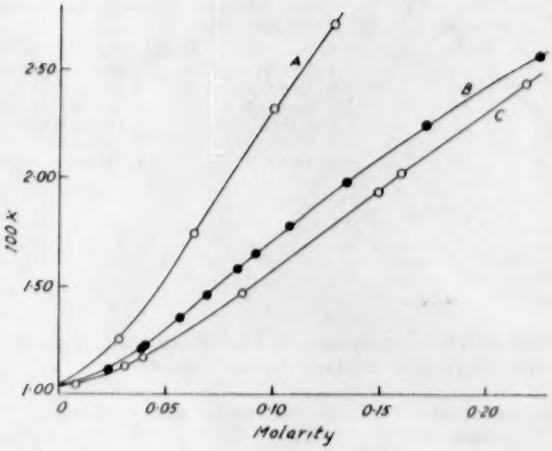


FIG. 2. *Comparison of the specific conductances of benzoic anhydride and some other electrolytes.*

A, K_2SO_4
B, $(Ph{\cdot}CO)_2O$
C, $Ph{\cdot}CO_2H$

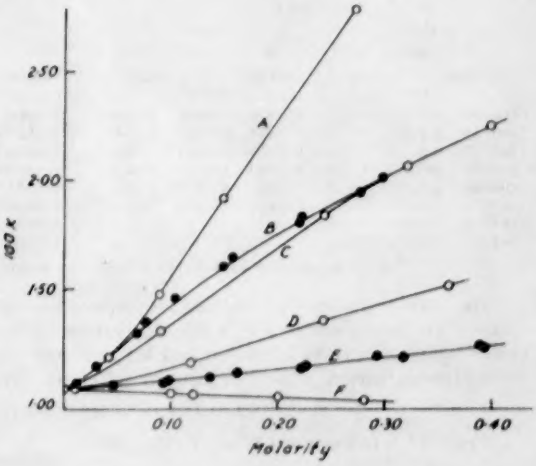


FIG. 3. *Comparison of the specific conductances of succinic and phthalic anhydrides and some other electrolytes.*

A, $Me{\cdot}CO_2H$
B, $CH_2{\cdot}CO\!>\!O$ / $CH_2{\cdot}CO$
C, CH_2–C_6H_4–NO_2
D, $CHCl_2{\cdot}CO_2H$
E, $C_6H_4(CO)_2O$
F, SO_2Cl_2

sulphate ion concentration will be slightly increased resulting in a slightly greater conductivity. From the equilibrium constant for the above reaction, $K_b[HS_2O_7^-] = 0{\cdot}008$ mole kg.$^{-1}$, it may be shown that at 10° the $HS_2O_7^-$ ion is solvolysed to the extent of approximately 12% in a 0·1M-solution. The value of the equilibrium constant is not known at 25°, but it does not appear unreasonable that the specific conductivities of acetic and benzoic anhydrides at this concentration exceed those of a monohydrogen sulphate by approximately 10%.

Conductivities of Acetic and Benzoic Acids in Dilute Oleums.—The conductivities of solutions of acetic and benzoic acids in dilute oleums were measured. The results are given in Table 3 and Fig. 4. The specific conductance decreases on the addition of acetic or benzoic acid to an oleum, passes through a minimum and then begins to rise again before

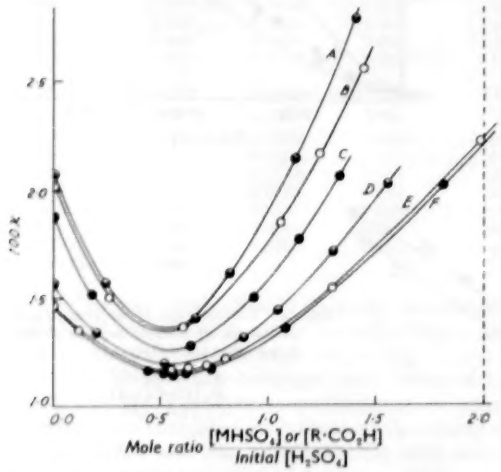


FIG. 4. *Specific conductances of acetic and benzoic acids and ammonium and potassium hydrogen sulphates in oleum solutions.*

	Initial $H_2S_2O_7$ concn.
A, $NH_4{\cdot}HSO_4$	0·2668m
B, $Me{\cdot}CO_2H$	0·2387m
C, $Ph{\cdot}CO_2H$	0·1961m
D, $KHSO_4$	0·1177m
E, $Me{\cdot}CO_2H$	0·0937m
F, $Ph{\cdot}CO_2H$	0·0951m

one mole of carboxylic acid has been added for each mole of disulphuric acid originally present, and continues to rise after this composition has been reached.

TABLE 3. *Specific conductances of solutions of acetic and benzoic acids in dilute oleums at 25°.*

Acetic acid						Benzoic acid					
m	Mole ratio	100κ	*m*	Mole ratio	100κ	*m*	Mole ratio	100κ	*m*	Mole ratio	100κ
Initial $H_2S_2O_7$ concn. = 0·0937m			Initial $H_2S_2O_7$ concn. = 0·2387m			Initial $H_2S_2O_7$ concn. = 0·0951m			Initial $H_2S_2O_7$ concn. = 0·1961m		
0·0000	0·0000	1·462	0·0000	0·0000	2·018	0·0000	0·0000	1·468	0·0000	0·0000	1·875
0·0116	0·1239	1·350	0·0626	0·2623	1·504	0·0425	0·4466	1·160	0·0354	0·1803	1·518
0·0517	0·5519	1·166	0·1444	0·6051	1·366	0·0489	0·5142	1·149	0·1268	0·6466	1·277
0·0591	0·6306	1·170	0·2520	1·0557	1·847	0·0524	0·5514	1·147	0·1832	0·9342	1·502
0·0666	0·7108	1·184	0·2950	1·2359	2·164	0·0591	0·6219	1·150	0·2233	1·1387	1·770
0·0753	0·8032	1·212	0·3441	1·4416	2·558	0·0695	0·7304	1·172	0·2606	1·3289	2·064
0·1219	1·3010	1·546				0·1030	1·0825	1·358			
0·1855	1·9793	2·215				0·1727	1·8156	2·020			

* Stoicheiometric mole ratio = moles of solute : initial moles of $H_2S_2O_7$.

The conductivities of solutions of ammonium and potassium hydrogen sulphate in oleum [5] are also given in Fig. 4 for comparison; the conductivities of these solutions are closely similar to those of acetic and benzoic acids in oleums of approximately the same initial concentration. Metal hydrogen sulphates ionise according to equation (4) and it

$$MHSO_4 + H_2S_2O_7 = M^+ + HS_2O_7^- + H_2SO_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

[5] Part XIII, Gillespie and Wasif, *J.*, 1953, 964.

may be reasonably concluded that acetic and benzoic acids ionise in an analogous manner [eqn. (5)] and this agrees with Leisten's conclusions from his cryoscopic measurements.[1]

$$R{\cdot}CO_2H + H_2S_2O_7 = R{\cdot}CO_2H_2^+ + HS_2O_7^- \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

According to equation (5) the highly conducting $H_3SO_4^+$ ions resulting from the ionisation of the disulphuric acid are replaced by the poorly conducting carboxylic acidium ions and hence the conductivity decreases at first. Although the conductivity begins to increase before the stoicheiometric mole ratio $R{\cdot}CO_2H : H_2S_2O_7 = 1 : 1$ is reached the actual value of the specific conductance at this composition is very small, certainly very much smaller than that of a mono(hydrogen sulphate) at the same concentration. This is consistent with equation (5) which indicates that at this composition the solution contains the electrolyte $R{\cdot}CO_2H_2^+,HS_2O_7^-$ both of whose ions have a very small mobility. The rise in the conductivity before this composition is reached can again be attributed to solvolysis of the hydrogen disulphate ion according to equation (3) which gives rise to a small amount of the highly conducting hydrogen sulphate ion.

Comparison of the Conductivities of Acetic and Benzoic Anhydrides in Sulphuric Acid with Acetic and Benzoic Acids in Dilute Oleums.—Further addition of acid up to, and beyond, the stoicheiometric mole ratio $R{\cdot}CO_2H : H_2S_2O_7 = 2 : 1$ causes an increase in the

$$R{\cdot}CO_2H + H_2SO_4 = R{\cdot}CO_2H_2^+ + HSO_4^- \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

conductivity which may be attributed to the ionisation (6). At the composition corresponding to this mole ratio the overall reaction may be written

$$2R{\cdot}CO_2H + H_2S_2O_7 + H_2SO_4 = 2R{\cdot}CO_2H_2^+ + HS_2O_7^- + HSO_4^- \quad . \quad . \quad . \quad (7)$$

and comparison with equation (1) shows that a solution of a carboxylic acid in oleum having a composition corresponding to the mole ratio 2 : 1 should be identical with a solution of half the concentration of the corresponding anhydride in 100% sulphuric acid. That the conductivities of such solutions are in fact the same may be seen from the results given in Tables 1 and 3. Thus a solution of 0·1874m-acetic acid in an oleum whose initial concentration of disulphuric acid was 0·0937m had a specific conductance of 0·0224 ohm^{-1} $cm.^{-1}$. This may be compared with the specific conductance of 0·0937m-acetic anhydride in 100% sulphuric acid which was 0·0220 ohm^{-1} $cm.^{-1}$. Similarly 0·1902m-benzoic acid in an oleum whose initial concentration was 0·0951m had a specific conductance of 0·0220 ohm^{-1} $cm.^{-1}$ compared with 0·0220 ohm^{-1} $cm.^{-1}$ for 0·0951m-benzoic anhydride in 100% sulphuric acid.

Succinic Anhydride.—The results of our measurements on succinic anhydride given in Tables 1 and 2 and in Fig. 3 show that it produces rather less than one hydrogen sulphate ion per molecule of anhydride. Its specific conductance is quite close to that of *p*-nitrotoluene, which has been shown by cryoscopic measurements to be approximately 70% ionised in a 0·1m solution.[6] Its mode of ionisation cannot be unambiguously established on the basis of our conductivity measurements alone. Thus our observations are consistent with a partial ionisation according to an equation analogous to equation (1), *i.e.*, (8), or

$$\begin{matrix} CH_2{\cdot}CO \\ | \quad >O \\ CH_2{\cdot}CO \end{matrix} + 3H_2SO_4 = \begin{matrix} CH_2{\cdot}CO_2H_2^+ \\ | \\ CH_2{\cdot}CO_2H_2^+ \end{matrix} + HSO_4^- + HS_2O_7^- \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

equally with an incomplete simple protonation according to equation (9) or with the

$$\begin{matrix} CH_2{\cdot}CO \\ | \quad >O \\ CH_2{\cdot}CO \end{matrix} + H_2SO_4 = \begin{matrix} CH_2{\cdot}CO \\ | \quad >OH \\ CH_2{\cdot}CO \end{matrix} + HSO_4^- \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

incomplete formation of an acyl ion [equation (10)] or with a combination of any two or all three of these ionisations.

$$\begin{matrix} CH_2{\cdot}CO \\ | \quad >O \\ CH_2{\cdot}CO \end{matrix} + H_2SO_4 = \begin{matrix} CH_2{\cdot}CO \\ | \\ CH_2{\cdot}CO_2H \end{matrix} + HSO_4^- \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

[6] Part VII, Gillespie, *J.*, 1950, 2542.

By means of cryoscopic measurements in slightly aqueous sulphuric acid, Oddo and Casalino [7] found that succinic anhydride had an *i*-factor increasing from approximately 1·2 to 1·8 with increasing concentration of the anhydride. This suggests that equation (8) most nearly represents the ionisation of succinic anhydride, the low *i*-factors and their dependence on concentration being due to the reaction of the anhydride with the water initially present in the solvent [equation (11)].

$$\begin{matrix}CH_2{\cdot}CO\\ |\\ CH_2{\cdot}CO\end{matrix}\!\!>\!O + H_3O^+ + H_2SO_4 = \begin{matrix}CH_2{\cdot}CO_2H_2^+\\ |\\ CH_2{\cdot}CO_2H_2^+\end{matrix} + HSO_4^- \quad . \quad . \quad . \quad . \quad (11)$$

It has been shown by cryoscopic measurements [7,8,9] that succinic acid has an *i*-factor of approximately 2·5, which suggests, although it does not prove, that it undergoes simple protonation, the second stage of ionisation being incomplete; this is consistent with our conclusion that if, as seems likely, the ionisation of succinic anhydride occurs according to equation (8), it is incomplete. It may be regarded as occurring in three stages: (*a*) the removal of water from the solvent to form the acid [eqn. (12)], (*b*) monoprotonation of the

$$\begin{matrix}CH_2{\cdot}CO\\ |\\ CH_2{\cdot}CO\end{matrix}\!\!>\!O + 2H_2SO_4 = \begin{matrix}CH_2{\cdot}CO_2H\\ |\\ CH_2{\cdot}CO_2H\end{matrix} + H_2S_2O_7 \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

acid by disulphuric acid, which is essentially complete [eqn. (13)], (*c*) incomplete diprotonation of the acid by the solvent [eqn.(14)].

$$\begin{matrix}CH_2{\cdot}CO_2H\\ |\\ CH_2{\cdot}CO_2H\end{matrix} + H_2S_2O_7 = \begin{matrix}CH_2{\cdot}CO_2H_2^+\\ |\\ CH_2{\cdot}CO_2H\end{matrix} + HS_2O_7^- \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$\begin{matrix}CH_2{\cdot}CO_2H_2^+\\ |\\ CH_2{\cdot}CO_2H\end{matrix} + H_2SO_4 = \begin{matrix}CH_2{\cdot}CO_2H^+\\ |\\ CH_2{\cdot}CO_2H_2^+\end{matrix} + HSO_4^- \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Further cryoscopic and conductivity measurements are, however, needed before any firm conclusions concerning the ionisation of succinic anhydride can be reached.

Phthalic Anhydride.—Our results on phthalic anhydride (Tables 1 and 2, Fig. 3) indicate that it is considerably less ionised or, more exactly, produces considerably less hydrogen sulphate ion, than succinic anhydride. It is probably ionised only to the extent of 10% or less. Again we cannot decide on the mode of ionisation on the basis of conductivity results alone.

In order to obtain some further information we measured freezing-point depressions produced by phthalic anhydride in sulphuric acid, using sulphuric acid containing a little potassium sulphate to repress the autoprotolysis; the results are given in Table 4. Column

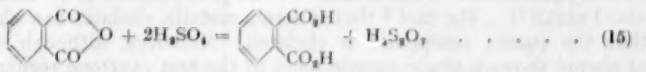
TABLE 4. *Freezing-points of solutions of phthalic anhydride in sulphuric acid.*

m_2	F. p.	$\Delta\theta$	ν'	m_2	F. p.	$\Delta\theta$	ν
Molality of K_2SO_4 (m_3) = 0·0656				Molality of K_2SO_4 (m_3) = 0·0544			
0·0000	8·875°	—	—	0·0000	9·180°	—	—
0·0372	8·645	0·230	1·03	0·0115	9·100	0·080	1·15
0·0677	8·413	0·462	1·14	0·0293	8·975	0·205	1·16
0·0880	8·268	0·607	1·15	0·0489	8·832	0·348	1·18
0·1080	8·134	0·741	1·14	0·0675	8·714	0·464	1·14

4 of this table gives ν', the approximate value of the number of moles of particles produced in solution by one mole of the solute, calculated by means of the equation $\Delta\theta/m_2 = 6{\cdot}12\,\nu'\,(1 - 0{\cdot}0039\theta)[1 + (m_2 - 6m_3)/2m_1)]$, where m_1 and m_2, are the molalities of sulphuric acid and solute respectively, which is an extended and slightly modified form of equation 2 of Part XIX [10] which allows for the presence of the second electrolyte potassium sulphate ($\nu_3 = 4$, $s_3 = 1$. Cf. equation 4 of Part I [11]). The mean value of ν' is 1·15,

[7] Oddo and Casalino, *Gazzetta*, 1917, **47**, II, 232.
[8] Wiles, *J.*, 1953, 986.
[9] Hantzsch, *Z. phys. Chem.*, 1907, **61**, *A*, 257.
[10] Part XIX, Flowers, Gillespie, and Oubridge, *J.*, 1956, in the press.
[11] Part I, Gillespie, Hughes, and Ingold, *J.*, 1950, 2473.

which is consistent with the small percentage ionisation found from the conductivity measurements. Both the conductivity and the cryoscopic measurements are, however, consistent with very incomplete ionisation according to equations analogous to (8), (9), or (10). Earlier work provides additional information. Hantzsch concluded from the results of both cryoscopic and conductivity measurements that phthalic anhydride is a non-electrolyte, but this was disputed by Oddo and Casalino who found that in slightly aqueous sulphuric acid phthalic anhydride had an *i*-factor which increased with increasing concentration from 0·9 to 1·2. Leisten [1] has reported an unpublished observation of Brayford and Wyatt that in sulphuric acid containing a little water phthalic anhydride gives a molar freezing-point depression that is considerably less than that for a non-electrolyte. Thus the work of Oddo and Casalino and of Brayford and Wyatt suggests that phthalic anhydride removes water from the solvent to form phthalic acid, just as succinic anhydride probably gives succinic acid, *i.e.*, that it ionises in a manner analogous to that represented by equations (8) and (11). The degree of ionisation is certainly much smaller than that of succinic anhydride, however, and even the formation of the acid must itself be very incomplete :



(15)

Phthalic anhydride must exist in sulphuric acid largely in a non-ionised form. We may note, however, that Newman and Deno [12] obtained an *i*-factor of 1·8 for naphthalene-1 : 8-dicarboxylic anhydride and claimed that the anhydride was completely recovered on dilution of the solution with water; this suggests that it ionises as a simple base as represented by equation (9).

Further work is needed on phthalic anhydride and similar anhydrides before any definite conclusions concerning their ionisation can be reached. Although acyl ions are not formed in appreciable amounts by acetic and benzoic anhydrides, the possibility of their formation by succinic and phthalic anhydrides cannot be ruled out. In cases such as phthalic anhydride, where the removal of water from the solvent to form the acid takes place only incompletely, the extent of the reaction may depend largely on the composition of the solvent, and may vary considerably from slightly aqueous acids to dilute oleum and ionisation at these compositions should be investigated.

Experimental

Apparatus and Procedure.—The technique and apparatus for cryoscopic measurements have been described.[11] Conductivity measurements were made at 25° with an improved form of the apparatus used by Gillespie and Wasif [13] which will be fully described later.[14]

Materials.—Sulphuric acid and oleums were prepared as described by Gillespie and Oubridge.[15] 100% Sulphuric acid was obtained by adding aqueous acid to a dilute oleum until its conductivity was a minimum (the composition of "minimum conductivity" acid differs very slightly from 100% H_2SO_4,[16,15] but the difference is negligible for the present work).

"AnalaR" acetic anhydride was distilled and the middle fraction (b. p. 137—138°) collected. Benzoic anhydride, twice recrystallised from benzene–light petroleum (b. p. 40—60°) and dried *in vacuo* at 100° had m. p. 41·5°. Succinic anhydride, crystallised from acetic anhydride, washed with dry ether, and dried *in vacuo* at 100°, had m. p. 119·5°. Phthalic anhydride, crystallised from chloroform and dried *in vacuo* at 100°, had m. p. 132°. "AnalaR" acetic acid was purified by fractional freezing. "AnalaR" benzoic acid, recrystallised from water and dried *in vacuo* at 100°, had m. p. 122°.

We thank the Ministry of Education for a scholarship (to R. F.).

William Ramsay and Ralph Forster Laboratories,
University College, London, W.C.1. [*Received, September 8th, 1955.*]

[12] Newman and Deno, *J. Amer. Chem. Soc.*, 1951, **73**, 3651.
[13] Part IX, Gillespie and Wasif, *J.*, 1953, 204.
[14] Gillespie and Solomons, to be published.
[15] Part XVII, Gillespie and Oubridge, *J.*, 1956, 80.
[16] Kunzler and Giauque, *J. Amer. Chem. Soc.*, 1952, **74**, 804.

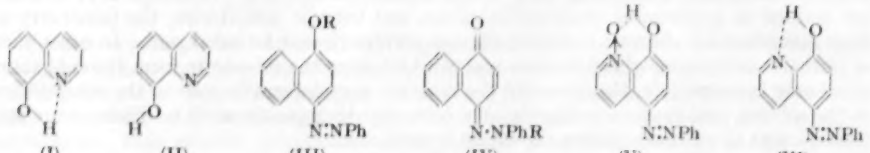
122. *Aromatic Azo-compounds. Part VIII.* A Study of Intramolecular Hydrogen Bonding in 8-Hydroxyquinoline.*

By G. M. Badger and R. G. Buttery.

4-Phenylazo-1-naphthol exists in solution as an equilibrium mixture of the azo- and the phenylhydrazone tautomer. Similar tautomerism is shown to occur with 8-hydroxy-5-phenylazoquinoline, but this exists predominantly in the azo-form. With 8-hydroxy-5-phenylazoquinoline *N*-oxide, little or none of the phenylhydrazone tautomer is present. It is suggested that the position of the equilibrium is affected by the presence of a weak intramolecular hydrogen bond in 8-hydroxy-5-phenylazoquinoline and a very strong bond of the same type in its *N*-oxide.

The existence of intramolecular hydrogen bonding in 8-hydroxyquinoline can be inferred from its physical properties. Its m. p. is more than 100° below that of any of the isomeric hydroxyquinolines; it has a small wet m. p. depression (3°); and it is steam-volatile (see also Lutskii [1]). The fact [2] that it forms metallic chelates can also be taken as evidence that the parent compound is chelated. Moreover, although the infrared absorption of phenol shows a single intense band in the first overtone region at 7050 cm.$^{-1}$, that for 8-hydroxyquinoline shows two peaks of weak intensity around 6600 and 6830 cm.$^{-1}$ (both values estimated by inspection of the published curve).[3] Such twin peaks are typical of *ortho*-substituted phenols in which weak intramolecular hydrogen bonding can occur,[4] and the absorption can be similarly interpreted in terms of the two structures (I) and (II).

On the other hand, intramolecular hydrogen bonding in 8-hydroxyquinoline would involve the formation of a five-membered ring and it is widely held that for significant



(I) (II) (III) (IV) (V) (VI)

hydrogen bonding the ring must be six-membered (see, for example, Rodebush [5]); certainly the O–H · · · N distance is abnormally large for hydrogen bonding. Hearn, Morton, and Simpson,[6] working with the ultraviolet spectra, furthermore could find no evidence for the existence of appreciable intramolecular hydrogen bonding in 8-hydroxyquinoline. In a new approach to this problem the absorption spectrum of 8-hydroxy-5-phenylazoquinoline has been compared with those of its *N*-oxide and of 4-phenylazo-1-naphthol.

4-Phenylazo-1-naphthol is known to exist in solution as an equilibrium mixture of the azo-form (III; R = H) and the quinone phenylhydrazone tautomer (IV; R = H), each of which has a characteristic absorption spectrum.[7] 4-Phenylazo-1-methoxynaphthalene (III; R = Me), a model for the azo-form, gives a simple absorption curve with a maximum at 3920 Å. In the same way 1 : 4-naphthaquinone methylphenylhydrazone (IV; R = Me), a model for the phenylhydrazone tautomer, gives a simple absorption curve with a

* Part VII, *J.*, 1955, 2816.

[1] Lutskii, *Zhur. obshchei Khim.*, 1954, **24**, 561; *Chem. Abs.*, 1955, **49**, 6260.
[2] Perekalin, *J. Gen. Chem.* (*U.S.S.R.*), 1951, **21**, 129.
[3] Wulf and Liddel, *J. Amer. Chem. Soc.*, 1935, **57**, 1464; Hilbert, Wulf, Hendricks, and Liddel, *Nature*, 1935, **135**, 147.
[4] Pauling, "Nature of the Chemical Bond," Cornell Univ. Press, New York, 1940, p. 320.
[5] Rodebush in "Advances in Nuclear Chemistry and Theoretical Organic Chemistry," ed. Burk and Grummitt, Interscience, New York, 1945, p. 151; cf. Wheland, "Advanced Organic Chemistry," Wiley, New York, 1949, p. 52.
[6] Hearn, Morton, and Simpson, *J.*, 1951, 3318.
[7] Kuhn and Bar, *Annalen*, 1935, **516**, 143; Burawoy, Salem, and Thompson, *J.*, 1952, 4793; Burawoy and Thompson, *J.*, 1943, 1443.

maximum at 4600 Å (see Fig. 1). The spectrum of 4-phenylazo-1-naphthol, however, consists of two broad bands, with maxima at 4080 Å (associated with the azo-form) and 4620 Å (phenylhydrazone tautomer) (Fig. 2), the relative intensities of the bands indicating that the azo-form occurs to a somewhat greater extent in ethanol solution. On the other hand, the phenylhydrazone tautomer is almost entirely absent from 8-hydroxy-5-phenylazoquinoline *N*-oxide (V) in ethanol. Strong intramolecular hydrogen bonding, involving the formation of a six-membered ring, would certainly be expected with this compound, and it seems that this is sufficient to shift the equilibrium almost entirely towards the azo-form.

The spectrum of 8-hydroxy-5-phenylazoquinoline (VI) shows two regions of absorption. The absorption associated with the phenylhydrazone tautomer is of relatively low intensity, and shows only a point of inflexion. Thus weak hydrogen bonding occurs in 8-hydroxy-5-phenylazoquinoline, and shifts the tautomeric equilibrium in favour of the azo-form.

The spectra of 8-hydroxy-5-phenylazoquinoline in a number of other solvents show small differences in the relative intensities of the two absorption bands, the absorption

FIG. 1. FIG. 2.

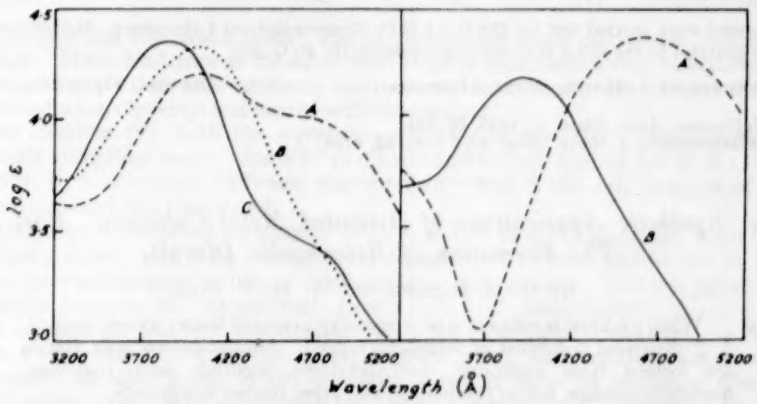


FIG. 1. *Absorption spectra of (A) 4-phenylazo-1-naphthol, (C) 8-hydroxy-5-phenylazoquinoline, and (B) 8-hydroxy-5-phenylazoquinoline N-oxide, in absolute ethanol.*

FIG. 2. *Absorption spectra of (A) naphtha-1 : 4-quinone methylphenylhydrazone and (B) 4-phenylazo-1-methoxynaphthalene, in absolute ethanol.*

due to the phenylhydrazone tautomer increasing in the order carbon tetrachloride, chloroform, ethanol, and acetic acid. This is not unexpected, for the greater the possibility of intermolecular hydrogen bonding the smaller would be the influence of weak intramolecular hydrogen bonding on the position of the equilibrium. The spectra of 8-hydroxy-5-phenylazoquinoline *N*-oxide in a series of solvents were identical except for slight shifts in the wavelength of the maxima; in this case it seems that the intramolecular hydrogen bond is so strong that intermolecular hydrogen bonding with the solvent is without effect on the equilibrium.

Most of the compounds used in this investigation were prepared essentially by recorded methods. 8-Hydroxy-5-phenylazoquinoline *N*-oxide was prepared by coupling 8-hydroxyquinoline *N*-oxide with benzenediazonium chloride.

EXPERIMENTAL

4-Phenylazo-1-naphthol.—This [8] was purified by several re-precipitations from alkali. Repeated recrystallisation from benzene gave a product, m. p. 205—206°.

1-Methoxy-4-phenylazonaphthalene.—4-Phenylazo-1-naphthol was methylated with methyl sulphate. After recrystallisation from ethanol the product had m. p. 82—83°.

Naphtha-1 : 4-quinone Methylphenylhydrazone.—Naphtha-1 : 4-quinone was condensed with

[8] Witt and Dedichen, *Ber.*, 1897, **30**, 2655.

N-methyl-*N*-phenylhydrazine sulphate according to McPherson's method.[9] After recrystallisation from ethanol the product had m. p. 117—118°.

8-Hydroxy-5-phenylazoquinoline.—A diazotised solution of aniline in dilute hydrochloric acid was added to a cold solution of 8-hydroxyquinoline in acetic acid.[10] The mixture was kept below 5° for 12 hr., after which the azo-compound was precipitated with aqueous ammonia. The crude product had m. p. 182—183°, raised to 185—185·5° by repeated recrystallisation from benzene.

8-Hydroxy-5-phenylazoquinoline N-Oxide.—A solution of benzenediazonium chloride [from aniline (3 g.) in concentrated hydrochloric acid (20 c.c.) and water (100 c.c.) with sodium nitrite (3 g.) in water (20 c.c.) at 0°] was gradually added to a solution of 8-hydroxyquinoline *N*-oxide (5 g.) and sodium hydroxide (30 g.) in water (4 l.) at 0°. After 2 hours' stirring at 0° the solid was collected and acidified with dilute acetic acid. *8-Hydroxy-5-phenylazoquinoline N-oxide* (6 g.), recrystallised from 1 : 1 benzene–light petroleum (b. p. 40—100°), formed orange needles, m. p. 183—184° (Found: C, 67·9; H, 4·1; N, 15·9. $C_{15}H_{11}O_2N_3$ requires C, 67·9; H, 4·2; N, 15·8%).

Absorption Spectra.—The absorption spectra were determined with a Hilger Uvispek Spectrophotometer.

Analyses were carried out by the C.S.I.R.O. Microanalytical Laboratory, Melbourne. We are also grateful to the C.S.I.R.O. for a scholarship (to R. G. B.).

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[9] McPherson, *Amer. Chem. J.*, 1899, **22**, 364.
[10] Cf. Matsumura, *J. Amer. Chem. Soc.*, 1930, **52**, 4164.

123. *Synthetic Applications of Activated Metal Catalysts. Part II.* The Formation of Heterocyclic Diaryls.*

By G. M. BADGER and W. H. F. SASSE.

When pyridine is refluxed with a specially prepared Raney nickel catalyst, 2 : 2′-dipyridyl is formed in satisfactory yield. Similar heterocyclic diaryls are formed from α-picoline, 4-ethylpyridine, nicotinic acid, quinoline, 6-methylquinoline, benzo[*f*]quinoline, and other related compounds.

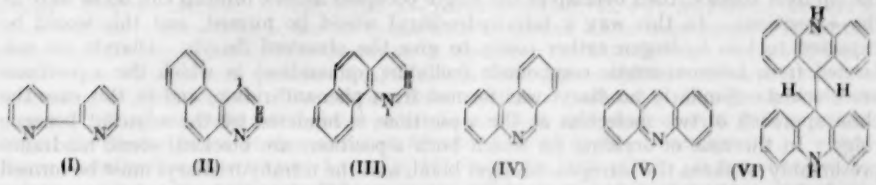
RANEY nickel is here reported as a useful catalyst for the preparation of heterocyclic diaryls. For example, pyridine, when refluxed with the catalyst, affords 2 : 2′-dipyridyl in useful yield on evaporation (and recovery) of the unchanged base. As 2 : 2′-dipyridyl and many related heterocyclic diaryls form characteristic metallic chelate compounds, the method should prove of value for the preparation of these valuable reagents.

In the preliminary experiments with pyridine, in which W7 Raney nickel [1] was used, the crude product was dark brown and was obtained only in small yield. Attempts were therefore made to modify and improve the catalyst for the present purpose, by treating it in various ways to reduce the amount of adsorbed hydrogen. The most satisfactory catalyst (see Experimental section) was obtained by heating W7 Raney nickel on a steam-bath in a vacuum. Pyridine was then added to the essentially dry (and pyrophoric) catalyst, with care to exclude air until the nickel had been completely covered. The addition of hydrogen acceptors (such as acetone and *cyclo*hexanone) to the reaction mixture was without influence on the yield, and a catalyst which had been deactivated with aqueous hydrogen peroxide was much less effective. Under the best conditions so far found, the crude 2 : 2′-dipyridyl was obtained as pale yellow crystals which could be purified without difficulty. From the liquors a little 2 : 2′ : 2″-terpyridyl was also obtained. In some runs a small amount of an insoluble organonickel compound was obtained. Pyrolysis of this material at atmospheric pressure gave a little volatile material which was identified as 2 : 2′-dipyridyl. This was also obtained when the organonickel compound was dissolved in warm concentrated hydrochloric acid, and the solution basified. It may be noted that

* The paper, *J.*, 1954, 4162, is regarded as Part I.
[1] *Org. Synth.*, 1949, **29**, 24.

similar organonickel compounds were obtained in small quantity when a few other heteroaromatic compounds were heated with the catalyst, but only when the latter had two free α-positions.

The reaction has also been examined with a number of related ring systems. Quinoline readily gave 2 : 2′-diquinolyl; and benzo[*f*]quinoline (II) gave 3 : 3′-di(benzo[*f*]quinolyl). Some 2 : 2′-di(benzo[*h*]quinolyl) was obtained from benzo[*h*]quinoline (III), but the yield was very poor and it is thought that steric hindrance may be involved here. It seems likely that dimerisation must be preceded by chemisorption of the nitrogen on to the



(I) (II) (III) (IV) (V) (VI)

nickel surface (see Discussion below), and the benzo-ring would offer steric hindrance at this stage. Steric hindrance at the subsequent stage of dimerisation may be involved with phenanthridine (IV), for this substance was recovered unchanged. No tetrapyridyl could be obtained when dipyridyl was heated with the catalyst.

With acridine (V), both the α-positions are blocked and this compound gave an apparently anomalous result. Some 9 : 10-dihydroacridine was formed, but 9 : 9′ : 10 : 10′-tetrahydro-9 : 9′-diacridinyl (VI) was also obtained. This is the only example of a γγ′-dimerisation which has been found.

*iso*Quinoline decomposed extensively (with evolution of much ammonia) when heated with Raney nickel, and little success could be achieved. When carried out in xylene solution the reaction gave an almost black organonickel product. This was pyrolysed at atmospheric pressure, and the sublimate gave a little 3 : 3′-di*iso*quinolyl.

The reaction has also been investigated with a few substituted derivatives. α-Picoline gave 6 : 6′-dimethyl-2 : 2′-dipyridyl, albeit in poor yield; and collidine was recovered unchanged. An alkyl group in the γ-position seems to have no inhibiting effect, for 4-ethylpyridine gave a very satisfactory yield of 4 : 4′-diethyl-2 : 2′-dipyridyl. No dimer could be obtained from 2-aminopyridine, or from 3 : 5-dibromopyridine. In the latter case it is of interest that dehalogenation did not occur to any extent under the conditions used.

Similar results were obtained with two quinoline derivatives: 6-methylquinoline gave 6 : 6′-dimethyl-2 : 2′-diquinolyl in satisfactory yield, but quinaldine was recovered unchanged. In the latter, no free α-position is available, and steric hindrance to chemisorption at the catalyst surface may also be a factor.

Nicotinic acid was also dimerised in aqueous sodium carbonate to give a dicarboxydipyridyl, probably 5 : 5′-dicarboxy-2 : 2′-dipyridyl. Similarly, in xylene solution, ethyl nicotinate gave a diethoxycarbonyldipyridyl, probably 5 : 5′-diethoxycarbonyl-2 : 2′-dipyridyl. In this case a little of an organonickel compound was also formed, which on hydrolysis with alcoholic potassium hydroxide gave 5 : 5′-dicarboxy-2 : 2′-dipyridyl.

Discussion.—The literature [2] records several methods for the preparation of 2 : 2′-dipyridyl by heating pyridine with various catalysts; but it is unlikely that the present method involves a simple dehydrogenation. The experimental conditions are mild, a temperature of about 115—150° being involved. It has also been found that platinised asbestos does not catalyse the formation of dipyridyl from pyridine even on 48 hours' refluxing, and it seems that the adsorbed hydrogen on the nickel catalyst must be essential to the reaction.

Pyridine and similar heteroaromatic compounds are known to be catalyst "poisons"

[2] *E.g.*, (*a*) Willink and Wibaut, *Rec. Trav. chim.*, 1935, **54**, 275; (*b*) Wibaut, Willink, and Nieuwenhuis, *ibid.*, p. 804; Hein and Retter, *Ber.*, 1928, **61**, 1790; Morgan and Burstall, *J.*, 1932, 20.

in hydrogenation reactions[3] and it seems to be accepted that such compounds use the nitrogen "lone pair" to form a covalent bond with the catalyst.[4] It is reasonable to suppose that such a bond is formed as the first stage in the present reaction. It is significant that the reaction proceeds only to a small extent when the approach to the nitrogen atom is sterically hindered, as in benzo[*h*]quinoline (III).

It is tentatively suggested that the next step may involve the addition of one atom of hydrogen (presumably to the nitrogen) to give a radical with a free valency at the α- or γ-position. When two such free radicals are formed sufficiently close to one another on the catalyst surface, then overlap of the singly occupied atomic orbitals can occur only at the α-positions. In this way a tetrahydrodiaryl would be formed, and this would be expected to lose hydrogen rather easily to give the observed diaryls. Diaryls are not formed from heteroaromatic compounds (collidine, quinaldine) in which the α-positions are blocked. Similarly no diaryl was formed from phenanthridine, and in this case the close approach of two molecules at the α-positions is hindered by the adjacent benzene rings. In the case of acridine (in which both α-positions are blocked) steric hindrance presumably weakens the nitrogen–catalyst bond, and the tetrahydrodiaryl must be formed *in solution* and not on the surface of the catalyst. This tetrahydrodiaryl is, of course, considerably more stable than the tetrahydrodiaryls postulated as intermediates in other cases.

Experimental

Preparation of Catalyst.—Nickel–aluminium alloy (125 g.) was added in portions to a solution of sodium hydroxide (160 g.) in water (600 c.c.) during 7—10 min. The reaction was carried out in a 2-l. conical flask immersed in an ice-bath and equipped with a very efficient stirrer, to control frothing (no alcohol was added to reduce frothing). The temperature quickly reached 80—85° and, as soon as the addition of alloy was complete, the cooling-bath was removed, stirring being continued to control the frothing. When the temperature began to fall the flask was immersed in a boiling-water bath, gentle stirring being continued for 30 min. The stirrer was then stopped and distilled water (600 c.c.) added. The supernatant liquid was decanted and the catalyst then washed by decantation with distilled water (8 × 500 c.c.). The wet catalyst was then transferred to a 3-necked flask fitted with a condenser (closed at the top with a stopper), a dropping funnel, and a connection to the water-pump. The flask was slowly evacuated and warmed on a water-bath, care being taken to avoid losses of catalyst by frothing. After 2 hr. at 100°/*ca.* 20 mm. the flask was removed from the steam-bath. The pyridine (or other heterocyclic derivative) was then added, *via* the dropping funnel, to the evacuated flask, care being taken to avoid access of air until the catalyst had been thoroughly wetted. The stopper was then removed and the mixture refluxed.

Pyridine.—Pyridine (250 c.c.) was refluxed in the presence of nickel catalyst prepared as above. After 11 hr. the catalyst was filtered off (pyrophoric !) and quickly washed with a little hot pyridine. Unchanged pyridine (225 c.c., plus washings) was then removed by distillation, and the residue extracted with boiling light petroleum (b. p. 60—80°). In some runs a small amount (up to 0·5 g.) of an insoluble organonickel compound was removed at this stage. The petroleum solution was purified by passage through a column of alumina, the solvent evaporated, and the resulting product recrystallised from light petroleum (b. p. 40°). The 2 : 2′-dipyridyl (20 g.) formed colourless prisms, m. p. and mixed m. p. 70·5—71·5°.

From sixteen experiments under varying experimental conditions, a yield of 60 g. of dipyridyl was obtained and recrystallised. From the combined mother-liquors a little 2 : 2′ : 2″-terpyridyl (1·0 g.) was obtained. After recrystallisation from light petroleum it had m. p. 88° (lit., 88—89°) (Found: C, 77·1; H, 4·7; N, 18·1. Calc. for $C_{15}H_{11}N_3$: C, 77·2; H, 4·75; N, 18·0%).

Quinoline.—Quinoline (100 g.) was refluxed at 12 mm. for 14 hr. with nickel catalyst (from 125 g. of alloy). Removal of the unchanged quinoline gave the crude product (5·0 g.) which was recrystallised once from ethanol. The 2 : 2′-diquinolyl formed colourless plates, m. p. and mixed m. p. 193—194° (lit., 194·5—195·5°).

Benzo[f]quinoline.—A solution of benzo[*f*]quinoline (47 g.) in sulphur-free xylene (230 c.c.) was refluxed over nickel catalyst (from 125 g. of alloy) for 5 hr. The separated catalyst was washed with boiling xylene (500 c.c.), after which the combined filtrates were concentrated to

[3] Lindlar, *Helv. Chim. Acta*, 1952, **35**, 446; Elsner and Paul, *J.*, 1953, 3156.
[4] Maxted, *Adv. Catalysis*, 1951, **3**, 129.

250 c.c. The pale yellow crystals which separated (2·0 g.) were collected and recrystallised from xylene. **3 : 3′-*Di*(*benzo*[f]*quinolyl*)** formed pale yellow needles, m. p. 300° (Found: C, 87·55; H, 4·7; N, 8·0. $C_{26}H_{16}N_2$ requires C, 87·6; H, 4·5; N, 7·9%). It gave a yellow solution in mineral acid and its xylene solution showed a blue fluorescence. The addition of cuprous ions to its solution in ethanol gave a chelate compound of the same colour as that given by 2 : 2′-diquinolyl.

Benzo[h]*quinoline.*—A solution of benzo[*h*]quinoline (35 g.) in xylene (170 c.c.) was refluxed with nickel catalyst (from 92 g. of alloy) for 12 hr. The crude product (0·1 g.) was recrystallised from xylene. The resulting **2 : 2′-*di*(*benzo*[h]*quinolyl*)** formed pale yellow needles, m. p. 280° (Found: C, 87·25; H, 4·7; N, 8·0. $C_{26}H_{16}N_2$ requires C, 87·6; H, 4·5; N, 7·9%). It gave a yellow solution in mineral acids, and its xylene solution showed a blue fluorescence. It did not form a chelate compound with cuprous ions under conditions in which di(benzo[*f*]quinolyl) does.

Acridine.—A solution of acridine (75 g.) in xylene (200 c.c.) was refluxed with nickel catalyst (from 150 g. of alloy) for 5 hr. The mixture became yellow at once and a white precipitate soon appeared. This was collected together with the catalyst, and washed with boiling xylene (200 c.c.). Concentration of the combined filtrates gave **9 : 10-dihydroacridine** (9 g.) which, after recrystallisation from ethanol, had m. p. 171—173° (lit., 172—173°). It was identified by oxidation with aqueous potassium dichromate and sulphuric acid to acridine, m. p. 109—110°. The filtrate from this material was evaporated to dryness and the residue chromatographed in light petroleum (b. p. 60—80°) on alumina. In this way a little acridine (2·0 g.), m. p. 110°, was recovered.

The contaminated catalyst was extracted for 3 days (Soxhlet) with pyridine. Filtration of the cooled extract gave **9 : 9′ : 10 : 10′-tetrahydro-9 : 9′-diacridinyl** (12 g.). Lehmstedt and Hundertmark's method[5] gave material of m. p. 247—248° (lit., 249°, for higher-melting isomeride). It was characterised by treatment with sulphuric acid to give **1 : 2-di-(2-diphenylylamino)ethylene oxide**, which after recrystallisation from ethanol had m. p. 165° (Lehmstedt and Hundertmark[5] given m. p. 165°). On evaporation of the pyridine a dark residue was obtained which on chromatography gave acridine (5 g.), m. p. 109—110°. Re-examination of the catalyst showed that it still contained a considerable amount of tetrahydrodiacridinyl.

iso*Quinoline.*—A solution of redistilled *iso*quinoline (100 g.) in xylene (70 c.c.) was refluxed over nickel catalyst (from 125 g. of alloy) for 5 hr., considerable evolution of ammonia being noted. Evaporation of the filtrate (70 g. of *iso*quinoline recovered) gave a dark organonickel product which was pyrolysed (dull red heat) at atmospheric pressure. Extraction of the sublimate with benzene, and purification of the extract by chromatography on alumina, gave **3 : 3′-di*iso*quinolyl** (0·10 g.). After recrystallisation from benzene it had m. p. 195—196° (lit., 197—198°), and gave an intense orange chelate compound with ferrous ion in agreement with the literature.[6] (1 : 1′-Di*iso*quinolyl has m. p. 162—163° and does not form a chelate compound.)

α-*Picoline.*—The redistilled base (230 c.c.) was refluxed for 8 hr. with a catalyst (from 125 g. of alloy). After recrystallisation from light petroleum (b. p. 40°) the **6 : 6′-dimethyl-2 : 2′-dipyridyl** (0·85 g.) had m. p. 88—90° (Willink *et al.*[2a] give 89·5—90·5°). The picrate had m. p. 167—169° (lit., 170—171°).

4-*Ethylpyridine.*—The base (100 g.) was refluxed with catalyst (from 125 g. of alloy) for 17 hr. After removal of unchanged 4-ethylpyridine the residue was dissolved in benzene, a small amount (0·85 g.) of an organonickel compound being removed. The benzene extract yielded **4 : 4′-*diethyl*-2 : 2′-*dipyridyl*** (15 g.), b. p. 210°/30 mm., m. p. 38—40° (Found: C, 79·2; H, 7·4; N, 13·4. $C_{14}H_{16}N_2$ requires C, 79·2; H, 7·6; N, 13·2%). With ferrous ions it gave a chelate compound having the same colour as that from dipyridyl.

Phenanthridine, Collidine, 2-Aminopyridine, Quinaldine, 3 : 5-Dibromopyridine and 2 : 2′-Dipyridyl.—These compounds gave no dimeric product when refluxed with the catalyst.

6-*Methylquinoline.*—The base (97 g.) was refluxed (at 20 mm.) with the catalyst (from 125 g. of alloy) for 14 hr. The resulting **6 : 6′-*dimethyl*-2 : 2′-*diquinolyl*** (2 g.), recrystallised from benzene, formed colourless needles, m. p. 267° (Found: C, 84·1; H, 5·7; N, 9·95. $C_{20}H_{16}N_2$ requires C, 84·4; H, 5·7; N, 9·85). With cuprous ions it gave a chelate compound having the same colour as that from diquinolyl.

Sodium Nicotinate.—A solution of nicotinic acid (50 g.) in water containing a slight excess of sodium carbonate was refluxed for 8 hr. with the nickel catalyst (from 125 g. of alloy). There was a slight evolution of ammonia. After filtration, the catalyst was repeatedly extracted with

[5] Lehmstedt and Hundertmark, *Ber.*, 1930, **63**, 1229.
[6] Case, *J. Org. Chem.*, 1952, **17**, 471.

hot aqueous sodium carbonate. The filtrate was neutralised, and the resulting precipitate purified by dissolution in sodium carbonate and reprecipitation with acid. A much less soluble acid (1·0 g.) was separated from the unchanged nicotinic acid during this purification. It was further purified by several dissolutions in alkali and reprecipitations with acid. **5 : 5′(?)-*Dicarboxy*-2 : 2′-*dipyridyl*** was obtained as a white amorphous powder, m. p. >400° (Found : C, 59·0; H, 3·3; N, 11·4; O, 26·5. $C_{12}H_8O_4N_2$ requires C, 59·0; H, 3·3; N, 11·5; O, 26·2%). It was soluble in acids and bases, but insoluble in all common organic solvents. It could not be sublimed at 300°/0·01 mm. When suspended in ethanol it gave no chelate compound with ferrous ions, presumably because of its insolubility. Pyrolysis at a dull red heat gave 2 : 2′-dipyridyl, identified by comparison with an authentic specimen. (Willink *et al.*[3a] give m. p. 268—269° for 3 : 3′-dicarboxy-2 : 2′-dipyridyl.)

Ethyl Nicotinate.—A solution of the ester (53 g.) in xylene (220 c.c.) was refluxed over the catalyst (from 125 g. of alloy) for 21 hr. The catalyst was removed and washed with ethanol, and the ethanol removed from the combined filtrates by distillation. After being kept overnight the colourless product was collected and recrystallised from ethanol. **5 : 5′(?)-*Diethoxycarbonyl*-2 : 2′-*dipyridyl*** (4·85 g.) formed colourless needles, m. p. 148—149° (Found : C, 64·3; H, 5·4; N, 9·4. $C_{16}H_{16}O_4N_2$ requires C, 64·0; H, 5·4; N, 9·3%). It gave a purple chelate compound with ferrous ions.

The unchanged ethyl nicotinate (30 g.) was removed by distillation, and the residue extracted with boiling benzene. After chromatography, the benzene extract yielded a further 0·25 g. of the diester. The benzene-insoluble portion (2·75 g.) was an organonickel compound, which at a dull red heat gave a small amount of volatile organic material, which gave a positive ferroin reaction. Another portion was boiled with ethanolic potassium hydroxide and filtered. The resulting residue was soluble in mineral acid and gave a positive test for nickel with dimethylglyoxime. The light brown filtrate was treated with charcoal and then neutralised to give dicarboxy-2 : 2′-dipyridyl, identical with that obtained above.

Microanalyses were carried out by the C.S.I.R.O. Microanalytical Laboratory. We are also grateful to the C.S.I.R.O. for a scholarship (to W. H. F. S.), and to Dr. B. West for helpful discussions.

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124. *The Kinetics of the Reduction of Some Azo-compounds.*

By N. R. LARGE and SIR CYRIL HINSHELWOOD.

The kinetics of the reduction of a series of substituted azobenzenes by titanous chloride in aqueous alcohol have been studied. The reaction is of the first order with respect to the azo-compound and to titanous chloride, and the rate varies in a complex way with the concentration of hydrochloric acid. If the same active titanous species is to be postulated for the reduction of azo-, nitro-, and azoxy-compounds in this medium, then the simplest way of analysing the results is to set the concentration of the active titanous species proportional to $[HCl]^{-2}$. The effect of [HCl] on the concentration of the active azo-species is then expressed by a simple power series. These species seem to be singly- and doubly-protonated bodies.

In some examples the two stages of reduction, azo → hydrazo, and hydrazo → amines, are comparable in speed, and in one case the kinetics of the consecutive reactions are worked out.

The influence of substituents is complex, and appears to be the result of opposing effects, on the one hand on the process of electron transfer from the reducing agent, and on the other on the equilibrium between protonated and non-protonated azo-species. There are indications that changes in the former are reflected mainly in the activation energy, and changes in the latter in the non-exponential factor of the Arrhenius equation. This state of affairs results in an absence of additivity in free energies of activation.

THIS work continues the study of the reduction of azo-compounds by titanous chloride begun by Large, Stubbs, and Hinshelwood [1] and the general study of the kinetics of

[1] Large, Stubbs, and Hinshelwood, *J.*, 1954, 2736.

reductions by that agent.[2] The kinetics of the reaction vary quite considerably from compound to compound and certain cases furnish interesting examples of second-order consecutive reactions, or of autocatalytic effects. The study of the influence of substituent groups on the rate reveals some slightly unusual energy–entropy relations, and the dependence of the rate on the concentration of acid in the medium proves to be of interest.

For purposes of comparison the reduction of azobenzene by stannous chloride has also been studied as part of the attempt to distinguish effects of the acid on the titanous chloride reducing agent from those on the azo-compound.

Experimental

The following reagents were used: a solution of titanous chloride in hydrochloric acid standardised with "AnalaR" ferric ammonium sulphate, in turn standardised against pure potassium dichromate; a solution in hydrochloric acid of stannous chloride, standardised by addition of iodine and titration with sodium thiosulphate solution, potassium iodate being used as a primary standard; azobenzene and 4-hydroxyazobenzene supplied commercially; 2-amino-azobenzene prepared by a slight modification of Witt's method.[3] The other azo-compounds used were kindly given by Imperial Chemical Industries Limited, Dyestuffs Division. The compounds were recrystallised as necessary. The small amounts of the *cis*-isomers taken to be present were removed by Hartley's method,[4] assumed to be generally applicable.

The experimental procedure adopted for the measurement of reaction rates was that described by Large *et al.*[1] It consisted in the spectrophotometric determination of the residual azo-compound. The following modifications in detail were introduced. (i) In the experiments with 2 : 4 : 4′-triaminoazobenzene, 2 : 2′ : 4-trihydroxyazobenzene, and 4-amino-2′ : 4′-dihydroxyazobenzene the reaction was stopped when desired by sufficiently copious dilution of the solution with a suitable acid–alcohol mixture. With 2 : 2′ : 4-trihydroxyazobenzene experiments were carried out both with an acid–alcohol mixture and with ferric alum solution as quenching reagent. (ii) Since 2-aminoazobenzene undergoes spontaneous decomposition in presence of acid, quenching of mixtures containing it was effected by a solution of sodium hydroxide, the precipitate being removed by centrifuge. (iii) No suitable quenching reagent could be found for stannous chloride, and when this was used samples of the reaction mixture were transferred directly to the "Unicam" cells, the times at which the actual readings were made being taken as the reaction times. The experiments were made at 20·0° to ensure that very little change of temperature should occur in the time between sampling and examination. (iv) "End-point" determinations were carried out both with excess of the azo-compound and with excess of the reducing agent.

Results

2 : 4-*Diaminoazobenzene.*—End-point determinations with an excess of titanous chloride indicate that reduction to primary amines is quantitative. With excess of the azo-compound, however, the amount of it consumed is greater than would be expected if it were fully reduced. There is evidently competition for the available titanous chloride between the azo-compound itself and the hydrazo-compound formed in the first stage of its reduction. The two stages of the reaction: azo-compound ⟶ hydrazo-compound ⟶ products, must therefore proceed at comparable rates. The reduction is autocatalytic, some of the reaction–time curves being S-shaped, and the addition of reaction products causing a large increase in the rate (Table 1). Values of k_1 were therefore calculated from initial rates, a procedure which is valid since the reaction is followed by the decrease in concentration of the azo-body and not by the consumption of titanous chloride.

2-*Aminoazobenzene.*—End-point determinations indicate that reduction is quantitative. The reaction is autocatalytic. Some decomposition of the azo-compound occurs in acid solution. The methods used for the calculation of rate constants are discussed later.

2 : 4 : 4′-*Triaminoazobenzene.*—End-point determinations again indicate that the two stages of the reduction are of comparable speed, and the reaction is found to be autocatalytic. Rate constants were therefore calculated from initial rates.

4-*Hydroxyazobenzene.*—End-point determinations indicate quantitative reduction, and the course of the reaction with time is found to follow the second-order law. Rate constants were therefore calculated in the usual way.

[2] Newton, Stubbs, and Hinshelwood, *J.*, 1953, 3384; Stephen and Hinshelwood, *J.*, 1955, 1393.
[3] Witt, *Ber.*, 1912, **45**, 2380.
[4] Hartley, *J.*, 1938, 633.

2 : 2′ : 4-*Trihydroxyazobenzene.*—The rates of the two stages of the reduction are comparable, and although for high acid concentrations satisfactory bimolecular rate constants can be calculated, for low acid concentrations the problem of consecutive second-order reactions has had to be solved by a method which is discussed later.

4-*Amino*-2′ : 4′-*dihydroxyazobenzene.*—The reduction to the primary amines is quantitative and satisfactory second-order rate constants can be calculated.

Order of Reaction.—The order of reaction was investigated for several of the compounds studied, and for each the rate was found to be proportional to the concentration of titanous chloride and to that of the azo-compound, as was found for the reduction of azobenzene and 4-aminoazobenzene.[1] Typical results for one of the compounds (2 : 4-diaminoazobenzene) are given in Table 1.

TABLE 1. *Reduction of* 2 : 4-*diaminoazobenzene : order of reaction.*

[HCl] = 3·293N. Temperature 25·0°.

10^4 [Azo] (mole l.$^{-1}$)	7·73	7·73	7·73	7·73	5·80	3·86	1·93	3·8 *	3·8 *	3·8 *
10^4 [$TiCl_3$] (mole l.$^{-1}$)	30·9	23·2	15·5	7·73	30·9	30·9	30·9	15·0	15·0	15·0
10^6 Initial rate (mole l.$^{-1}$ min.$^{-1}$)	4·20	3·15	2·25	1·10	3·40	1·95	1·00	3·00	3·20	2·36
$10^2 k_1$ (sec.$^{-1}$ l. mole^{-1})	2·92	2·92	3·13	3·06	3·15	2·71	2·78	8·77	9·36	6·90

* In these experiments the products from an " infinity " run were added to the other reagents, the values given for the various concentrations being the concentrations in the resulting reaction mixture.

Effect of Acid Concentration.—The effect of acid concentration on the rate for various compounds is shown in Table 2. Its effect on the rate of reduction of azobenzene by stannous chloride was also studied, and the results are included in Fig. 2.

TABLE 2. *Effect of acid concentration.*

2 : 4-Diaminoazobenzene

[HCl] (mole l.$^{-1}$) ...	0·128	0·257	0·367	0·515	0·701	0·905	1·326	1·805	2·310	2·835	3·293
$10^2 k_1$ (sec.$^{-1}$ l. mole^{-1})	10·8	6·26	5·91	6·26	8·00	8·00	11·5	12·2	17·4	24·1	29·3

2-Aminoazobenzene

[HCl] (mole l.$^{-1}$)	0·099	0·257	0·515	0·937	1·335	2·310	3·121	3·263
k_1 (Method I)	0·970	0·960	0·523	0·462	0·510	0·420	0·472	0·502
k_1 (Method II)	0·938	0·870	0·545	0·440	0·498	0·378	0·423	0·490

4-Hydroxyazobenzene

[HCl] (mole l.$^{-1}$)	0·122	0·257	0·405	0·515	0·677	0·937	1·335	1·783	2·310	3·221	3·263
k_1	1·23	0·90	0·81	0·77	0·79	0·91	1·03	1·12	1·45	2·49	3·17

Activation Energies.—These were determined for 2 : 4-diaminoazobenzene, 4-hydroxyazobenzene, and 2 : 2′ : 4-trihydroxyazobenzene, and are given in Table 4 together with the values for azobenzene and 4-aminoazobenzene.

Kinetics of Consecutive Second-order Reactions.

In several examples, end-point determinations made with excess of each reagent in turn indicate that the rates of the two stages of the reduction are comparable. The kinetics of the reaction are therefore complicated by the finite accumulation of the hydrazo-compound formed in the first stage. If the amount of this intermediate present at any time is small, the rate of disappearance of the azo-compound itself is not much affected and the calculation of second-order rate constants by the usual formula is possible. When, however (as in the reduction of 2 : 2′ : 4-trihydroxyazobenzene at low acid concentrations), the concentration of the hydrazo-compound becomes considerable, the kinetics of consecutive second-order reactions have to be worked out before the complete course of the reaction–time curves can be expressed.

The initial stage of the reduction, that is to the hydrazo-compound, is of the first order with respect to the azo-compound and to the titanous chloride. If the reduction of the hydrazo-compound itself is assumed to be similarly of the first order with respect to each reagent, the equations for the rate of reaction may be formulated in the following way :

At time, t, [azo-compound] = A, [hydrazo-compound] = B, [$TiCl_3$] = T, and

$$\left.\begin{aligned} \mathrm{d}A/\mathrm{d}t &= -k_1AT \\ \text{and} \quad \mathrm{d}B/\mathrm{d}t &= k_1AT - k_2BT \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (1)$$

where k_1 and k_2 are the second-order rate constants for the first and the second stage of the reduction respectively.

Therefore $$dB/dA = k_2B/k_1A - 1$$

From this expression by integration

$$B = (A_0^{1-k}A^k - A)/(1 - k) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where $$k = k_2/k_1$$

When B reaches its maximum, $dB/dA = 0$ and $k = A_m/B_m$, where A_m and B_m are the values of A and B at this time.

Since each stage of the reduction requires two moles of titanous chloride for each mole of substrate, the concentrations of titanous chloride, azo-compound, and hydrazo-compound are related by

$$T_0 - T = 2B + 4(A_0 - A - B) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If the initial concentration of titanous chloride is chosen so as to be just sufficient to ensure quantitative reduction of the azo-compound to primary amines, then

$$T_0 = 4A_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Hence
$$-\frac{dA}{dt} = k_1A\left\{4A_0 - 4A_0 + 4A + 2\frac{(A_0^{1-k}A^k - A)}{1-k}\right\}$$

$$= k_1A\left\{\left(4 + \frac{2}{k-1}\right)A - \frac{2A_0^{1-k}A^k}{k-1}\right\}$$

$$= k_1A^2(4 + l - lA_0^{1-k}A^{k-1}), \text{ where } l = 2/(k-1)$$

Therefore $$-k_1 \cdot dt = dA/A^2(4 + l - lA_0^{1-k}A^{k-1})$$

This expression cannot be integrated directly, but can be expanded as a power series, which may then be integrated term by term:

$$\frac{dA}{A^2(4 + l - lA_0^{1-k}A^{k-1})} = \frac{dA}{A^2(4+l)}\left\{1 + \frac{lA_0^{1-k}}{(4+l)}A^{k-1} + \frac{l^2A_0^{2(1-k)}}{(4+l)^2}A^{2k-2} + \ldots\right\}$$

which on integration gives

$$-k_1t = \sum_{n=0}^{n=\infty} \frac{l^n}{(4+l)^{n+1}(nk - n - 1)}\left\{A_0^{n(1-k)}A^{(nk-n-1)} - A_0^{-1}\right\}$$

This forms a convergent series and it is therefore possible to evaluate k_1 from a limited number of terms. (For certain values of k the series becomes indeterminate, and other methods of integration have to be employed.)

The above formula was applied to the example of 2 : 2′ : 4-trihydroxyazobenzene as follows. One experiment was carried out with an acid–alcohol mixture as quenching agent, the values of A at various times being determined spectrophotometrically. In a second experiment ferric alum was added to the quenching reagent, so that, on standing, the hydrazo-compound present was completely reoxidised to the azo-compound. In this experiment the finally measured trihydroxyazobenzene concentration was then equal to $A + B$. The values of B calculated from these results are shown in Fig. 1. From this graph it was found that $dB/dt = 0$ when $t = 3{\cdot}0$, and at this point $A/B = 1{\cdot}42 = k$. Values of k_1 were then calculated from the first nine terms of the above expression for a series of values of A and t taken from the reaction–time curve (Fig. 1), and are given in Table 3. The error due to this approximation is well below 1%.

TABLE 3. *Reduction of 2 : 2′ : 4-trihydroxyazobenzene.*

$[TiCl_3] = 0{\cdot}00062$M. [Azo] $= 0{\cdot}000155$M. [HCl] $= 0{\cdot}257$N.
Temperature 25·0°.

t (min.)	1	2	3	4	5	6	7	8	9
10^4[Azo] (mole l.$^{-1}$)	1·006	0·745	0·567	0·446	0·366	0·322	0·286	0·256	0·226
k_1	13·1	12·3	12·5	12·8	12·9	12·4	12·1	11·9	12·1

As a check on the accuracy of the method, and on the correctness of the above interpretation of the experimental results, the reaction–time curve and the curve representing the formation of the hydrazo-compound were reconstructed by a method which did not involve the approximations used in the calculation of k_1. From a series of values of A the corresponding values of B were calculated by equation (2), and values of T were then obtained by equations (3) and (4). By the use of equation (1) in the form

$$-\mathrm{d}t/\mathrm{d}A = 1/k_1AT$$

a graph of $\mathrm{d}t/\mathrm{d}A$ against A was constructed. Integration of the equation gives $t_1 = \int_{A_2}^{A_1} \frac{\mathrm{d}t}{\mathrm{d}A}\mathrm{d}A$, and values of t were therefore obtainable by graphical integration. The reconstructed curves are shown in Fig. 1.

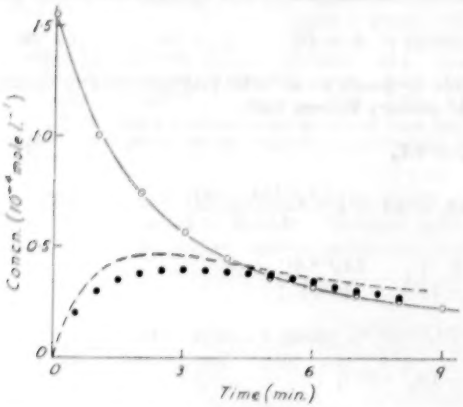


FIG. 1. *Reduction of 2 : 2′ : 4-trihydroxyazobenzene at low acid concentration.*

Consumption of azo-compound :
○ Experimental values.
—— Calculated curve.

Formation of hydrazo-compound :
● Experimental values.
– – – – Calculated curve

Spontaneous reaction of 2-aminoazobenzene.

In acid solution 2-aminoazobenzene undergoes a spontaneous reaction, probably a decomposition, and this has to be taken into account in the calculation of rate constants for the reduction by titanous chloride. Two methods were used.

Method I.—A series of values were calculated at various stages of the reduction for the expression $x/4ta(a-x)$, where a is the initial concentration of the azo-compound and $(a-x)$ the concentration at time t, the initial concentrations of 2-aminoazobenzene and titanous chloride being experimentally equivalent. These values were then extrapolated to zero reaction to give the apparent second-order rate constant k'. The decomposition reaction was assumed to be of the first order with respect to the azo-compound, so that if k_1 and k_0 are the rate constants for the reduction and decomposition respectively,

$$\mathrm{d}x/\mathrm{d}t = 4k_1(a-x)^2 + k_0(a-x)$$

and hence

$$k' = k_1 + k_0/4a$$

The values of k_0 obtained experimentally by following the disappearance of the azo-colour in the absence of titanous chloride were plotted against acid concentrations and the values of k' were then corrected by the use of values of k_0 read off this curve to give the values of k_1.

Method II.—Initial rates of change of the azo-compound were measured both in the presence and in the absence of titanous chloride, and from these the initial rates of the reduction were calculated. The values of the rate constant were obtained from these initial rates.

A comparison of the results obtained by the two methods is given in Table 2.

Autocatalytic effects.

With some of the azo-compounds used the phenomenon of autocatalysis is observed. Each of the compounds in question has an *o*-amino-substituent, so that one of the products must be an *o*-phenylenediamine, and it is therefore possible that a reactive complex is formed between the diamine and one of the reagents. Titanous salts are known to possess weak powers of complex

formation, and with an *o*-diamine might well give rise to complexes the reducing action of which would differ from that of the titanous chloride in its usual state. A possible alternative explanation is that the transient odd-electron intermediate, which is presumably formed as the first step in the reduction of the hydrazo-compound, is able to promote the reduction of the azo-compound, being itself re-oxidised to the hydrazo-compound.

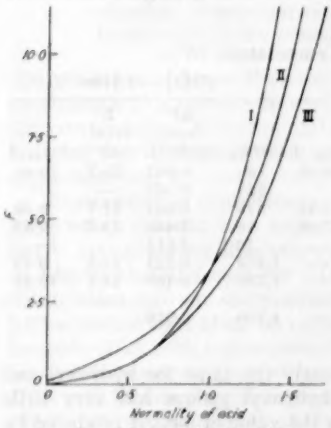
Discussion

Reaction Mechanism.—In a previous discussion [1] of the mechanism of reduction of azobenzene and 4-aminoazobenzene by titanous chloride it was suggested that the complete rate-equation is of the form

$$\text{Rate} = C^{-n}(\alpha C^2 + \beta C^4 + \gamma C^6 + \ldots\ldots)$$

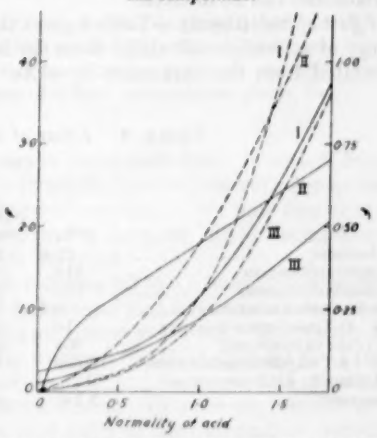
where C is the analytical concentration of hydrochloric acid. The term C^{-n} represents the effect of acid concentration on the reactive titanous species, and the rest of the expression the effect on the reactive azo-species.

Fig. 2. *Reduction of azobenzene by titanous chloride and by stannous chloride: functional relation to acid concentration.*



I. $F = 100k_1[HCl]^2$ for $TiCl_3$.
II. $F = 100k_1[HCl]$ for $TiCl_3$.
III. $F = k_1$ for $SnCl_2$.

Fig. 3. *Values of $k_1[HCl]$ and $k_1[HCl]^2$ for various azo-compounds.*



Left-hand scale: 4-aminoazobenzene (I), 4-hydroxyazobenzene (III).
Right-hand scale: 2-aminoazobenzene (II).

The function F in the various cases is as follows:

	I	II	III
Continuous lines	$10k_1[HCl]$	$k_1[HCl]$	$k_1[HCl]$
Broken lines	$10k_1[HCl]^2$	$k_1[HCl]^2$	$k_1[HCl]^2$

The rate of reduction of nitrobenzene is inversely proportional to the square of the acid concentration, and this can be accounted for by the assumption that the reactive species are $Ph{\cdot}NO_2H^+$ and $TiO(OH)_2$,[2] or, alternatively, $Ph{\cdot}NO_2$ and $Ti(OH)_2^+$. On the latter assumption the first step would be the transfer of an electron to the nitrobenzene molecule, the resultant ion then taking up a proton. In the reduction of azoxybenzene the rate is inversely proportional to the first power of the acid concentration, and this fact indicates that the reactive species are either $Ph{\cdot}NO{:}NPh$ and $Ti(OH)^{2+}$ or $Ph{\cdot}NO^+H{:}NPh$ and $Ti(OH)_2^+$. The medium used in each case was the same as that used in the present work for the reduction of azo-compounds. If the reactive titanous species is assumed to be the same in each case it will most probably be $Ti(OH)_2^+$. Accordingly, $n = 2$, from the equation $[Ti(OH)_2^+] = K[Ti^{3+}]/[H^+]^2$. This view receives some support from a consideration of the graphs of $k_1[HCl]$ and of $k_1[HCl]^2$ against $[HCl]$ for the reduction of azobenzene by titanous chloride (Fig. 2). The second, on the whole, has the appearance of a more probable

relation between the active azo-species and the acid concentration than the first, especially when values of these functions for several of the azo-compounds are compared (Fig. 3). It can be seen that while the graphs of $k_1[HCl]^2$ against [HCl] are all of a similar form, those of $k_1[HCl]$ against [HCl] vary considerably, and usually do not seem to correspond to any very likely function.

Over a considerable range the graph of $k_1[HCl]^2$ for the reduction of azobenzene by titanous chloride closely resembles that of k_1 for the reduction by stannous chloride (Fig. 2). This shows at any rate that the existence of a minimum in the curve of k_1 for the titanous reduction is not to be ascribed to variations in the titanous species alone, since the subsequent rapid increase is found with the stannous chloride reaction also. If the concentration of the active titanous species is assumed to be inversely proportional to the square of the acid concentration, then over the corresponding range the stannous species would be independent of the acid concentration and might be $SnCl_2(OH)^{2-}$. The species $SnCl_3^-$, which sometimes plays a part in the reactions of aqueous stannous chloride, could easily become important at higher acid concentrations. The above scheme depends upon the assumptions that the predominant titanous species in the solution is Ti^{3+} and that the reactive titanous species is the same throughout. Neither is certain, so that only general probabilities can be inferred.

Effect of Substituents.—Table 4 gives the values of the activation energy and of the free energy of activation calculated from the formula $\Delta F = -RT \ln k_1$. Values of $\log_{10} A$ are calculated from the expression $k_1 = Ae^{-E/RT}$. The introduction of a single substituent

TABLE 4. *Effect of substituents.* (Temperature 25°).

	[HCl] = 0·257N				[HCl] = 2·310N			
	10^3k_1	ΔF (kcal. mole^{-1})	E (kcal. mole^{-1})	$\log_{10} A$	10^3k_1	ΔF (kcal. mole^{-1})	E (kcal. mole^{-1})	$\log_{10} A$
Azobenzene	22·4	2·250	16·0	10·09	190	0·983	15·7	10·80
2-Aminoazobenzene	810	0·125	—	—	385	0·565	—	—
4-Aminoazobenzene	125	1·232	12·6	8·34	375	0·581	12·7	8·89
2 : 4-Diaminoazobenzene	6·3	3·001	12·6	7·04	16	2·448	13·2	7·89
2 : 4 : 4′-Triaminoazobenzene	10	2·727	—	—	12·1	2·614	—	—
4-Hydroxyazobenzene	904	0·0596	—	—	1,453	−0·221	12·3	9·18
2 : 2′ : 4-Trihydroxyazobenzene	12,500	−1·495	—	—	1,310	−0·160	14·1	10·46
4′-Amino-2 : 4-dihydroxyazobenzene	3,180	−0·684	—	—	4,700	−0·916	—	—

lowers the activation energy, and the change is very nearly the same for hydroxyl and amino-groups. The introduction of extra amino- or hydroxyl groups has very little further effect on the activation energy. The decrease in the value of $\log_{10} A$ produced by two amino-groups is nearly twice that produced by one. On the other hand, the introduction of hydroxyl groups into 4-hydroxyazobenzene causes an increase in $\log_{10} A$, while the introduction of a single hydroxyl group into azobenzene results in a decrease.

It seems likely that the reduction of azobenzene involves the setting up of equilibria between azobenzene and the ions $Ph{\cdot}N^+H{:}NPh$ and $Ph{\cdot}N^+H{:}N^+HPh$ followed by the transfer of an electron, and that these processes are the rate-determining ones.[1] Hydroxyl and amino-groups, by their inductive effects, should facilitate the electron transfer but reduce the equilibrium concentration of the protonated azo-species. The electromeric effect of hydroxyl will not assist the ease of electron transfer, but will facilitate the addition of protons. From a consideration of the results as a whole it appears that the activation energy, which is almost independent of the acid concentration, may well be mainly correlated with the electron-transfer process, while the probability factor may be determined mainly by the equilibria governing the concentrations of the protonated azo-species. The introduction of a single amino- or hydroxyl substituent seems to facilitate the electron transfer and reduces the activation energy to a limiting value, after which further substitution has little effect. The inductive effect of amino- and hydroxyl groups reduces the value of $\log_{10} A$, but where more than one hydroxyl group is introduced, the electromeric

effect, by making electrons available at the reaction centre, can more or less offset the reduction brought about by the inductive effect.

The pattern which emerges is one in which, clearly, there are superposed and conflicting effects at work. There is, it would seem in consequence of this, a conspicuous lack of the additivity in the energies or free energies of activation, which has sometimes been found. Such additivity appears to be characteristic of a mechanism in which a single step determined the rate. Where a number of simultaneous processes are of comparable importance and each plays some part in determining the rate, this additivity is evidently not to be found.

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125. *Modified Steroid Hormones. Part I. Some 4-Bromo-3-oxo-Δ⁴-derivatives.*

By D. N. KIRK, D. K. PATEL, and V. PETROW.

Bromination of some 3-oxo-Δ⁴-steroids (I) in ethylene or propylene oxide gives the corresponding 4-bromo-3-oxo-Δ⁴-steroids (II). The yields are significantly increased by passing the total bromination products through alumina. These bromo-compounds are also obtained, but in lower yields, by bromination in the presence of collidine.

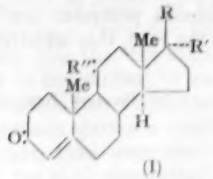
BROMINATION of 3-oxo-Δ⁴-steroids (I) with bromine in acetic acid–ether, or with *N*-bromosuccinimide in a suitable solvent, leads generally to allylic bromination with formation of the corresponding 6-bromo- and 2 : 6-dibromo-3-oxo-Δ⁴-steroids.[1] We now find that, by carrying out the bromination in the presence of a proton acceptor, allylic bromination is suppressed and 4-bromo-3-oxo-Δ⁴-steroids (II) are obtained.

Bromination of cholestenone (I*a*) in acetic acid–collidine led to a new monobromo-derivative which differed from authentic 2α-bromo-,[2] 6α-bromo-,[3] and 6β-bromo-cholest-4-en-3-one.[4] Its ultraviolet absorption spectrum showed a maximum at 261 mμ. The constitution of 4-bromocholest-4-en-3-one (II*a*) is consequently assigned to this compound as α-bromo-substitution into an αβ-unsaturated ketone (max. *ca.* 240 mμ) is known [5] to result in a bathochromic shift of *ca.* 23 mμ in the absorption maximum. In addition, reaction of the bromide (II*a*) with *o*-phenylenediamine in acetic acid leads to the quinoxaline derivative previously obtained from cholestane-3 : 4-dione.[6] Surprisingly, reaction of the bromide (II*a*) with lithium fluoride in dimethylformamide, with lithium chloride in collidine, or less effectively with collidine alone, leads to cholesta-4 : 6-dien-3-one. Extension of the bromination to testosterone propionate (I*b*) and to progesterone (I*c*) led to 4-bromotestosterone propionate (II*b*) and 4-bromoprogesterone (II*c*), respectively, severally characterised by their absorption maxima.

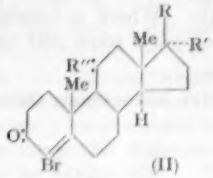
The yields of 4-bromo-steroids obtained as above ranged from 5% (II*b*) to 30% (II*c*). We therefore turned our attention to the use of proton-acceptors other than collidine in the hope of improving the yields, particularly of the testosterone derivative. By using ethylene or propylene oxide as proton acceptor, the yields of 4-bromo-3-oxo-Δ⁴-steroids (II) were substantially raised, particularly if the solutions of the total bromination products were percolated through short columns of alkaline aluminium oxide. In this way, the bromides (II*a*, *b*, and *c*) were obtained in yields exceeding 50%. The reaction was also

[1] See Djerassi, Rosenkranz, Romo, Kaufmann, and Pataki, *J. Amer. Chem. Soc.*, 1950, **72**, 4534.
[2] Djerassi, *ibid.*, 1949, **71**, 1003; see Jones, Ramsay, Herling, and Dobriner, *ibid.*, 1952, **74**, 2828, for stereochemistry of 2 : 4-dibromocholestan-3-one.
[3] Barton and Miller, *ibid.*, 1950, **72**, 1066.
[4] Ruzicka, Bosshard, Fischer, and Wirz, *Helv. Chim. Acta*, 1936, **19**, 1147; see ref. 3 for stereochemistry of the bromine atom.
[5] Nussbaum, Mancera, Daniels, Rosenkranz, and Djerassi, *J. Amer. Chem. Soc.*, 1951, **73**, 3263.
[6] Butenandt, Schramm, Wolff, and Kudszus, *Ber.*, 1936, **69**, 2779; Inhoffen, *Ber.*, 1937, **70**, 1695.

extended to the preparation of 4-bromo-17α-hydroxy- (II*d*) and 4-bromo-11-oxo-progesterone (II*e*) from 17α-hydroxy- (I*d*) and 11-oxo-progesterone (I*e*), respectively. *Inter alia*, the need for the alumina treatment referred to above argues for the presence in the bromination products of some 4ξ : 5ξ-dibromide which may be expected to pass into the monobromides (II) under the influence of the basic reagent.[7]



(I)



(II)

(*a*) R = C_8H_{17}, R' = H, R'' = H_2. (*d*) R = COMe, R' = OH, R'' = H_2.
(*b*) R = O·COPr, R' = H, R'' = H_2. (*e*) R = COMe, R' = H, R'' = O.
(*c*) R = COMe, R' = H, R'' = H_2.

Experimental

Ultraviolet absorption spectra were kindly determined by Mr. M. Davies, B.Sc., for EtOH solutions. Optical rotations were measured in $CHCl_3$ solution in a 1-dm. tube.

4-Bromocholest-4-en-3-one (II*a*).—(i) Cholestenone (3 g.) in anhydrous ether (30 ml.) and collidine (10 ml.) was treated with bromine in acetic acid (30 ml. of 1·05M; 4 mols.) in the dark at 20—25° for 48 hr. Collidine hydrobromide separated. The mixture was poured into water and extracted with ether which was then successively washed with dilute hydrochloric acid, dilute sodium hydrogen carbonate solution, and water, and dried. After removal of ether the residue was crystallised from ethanol to give *4-bromocholest-4-en-3-one*, slightly coloured needles, m. p. 113°, $[\alpha]_D^{27}$ +110° (*c* 0·472), $\lambda_{max.}$ 261—262 mμ (log ε 4·08) (Found: C, 70·3; H, 9·4; Br, 16·8. $C_{27}H_{43}OBr$ requires C, 69·9; H, 9·4; Br, 17·2%). Removal of colour was achieved by percolating a solution of the material in benzene–light petroleum (1 : 1) through a column of alumina (B.D.H., chromatography grade; 15 g.). The use of excess of bromine was necessary, otherwise lower yields were obtained.

(ii) Cholestenone (5 g.) in ethylene oxide (40 ml.) at −30° was treated with bromine in acetic acid (13·5 ml. of 0·985M) and kept at −30° in the dark for 20 hours. The product, isolated with ether as above, was percolated in benzene–light petroleum through alumina (50 g.), and the product crystallised from ethanol. *4-Bromocholestenone* formed needles, m. p. 113—114°, $[\alpha]_D^{20}$ +110° (*c* 0·472), $\lambda_{max.}$ as above (Found: Br, 18·7%), not depressed on admixture with a sample prepared as under (i).

Chromatography, on alumina, of the oily residues left after removal of the product (II*a*) failed to furnish a crystalline product.

Reaction of the bromide with silver acetate in pyridine–ether under reflux gave an oil which failed to yield a solid product on chromatography or treatment with dinitrophenylhydrazine.

The quinoxaline derivative of cholestane-3 : 4-dione was formed as pale brown plates, m. p. 205—207°, $\lambda_{max.}$ 239 (log ε 4·48) and 321 mμ (log ε 4·00) (Found: N, 5·8. Calc. for $C_{33}H_{48}N_2$: N, 5·9%) [after crystallisation from methylene chloride–ethanol (1 : 3) and from ethyl acetate], by heating the bromide (500 mg.) with *o*-phenylenediamine (125 mg.) in acetic acid (5 ml.) under reflux for 2 hr., dilution with methanol (5 ml.), and chilling (lit.,[6] m. p. 207—208°).

Cholesta-4 : 6-dien-3-one.—(i) The ketone (I*a*) (500 mg.) and lithium fluoride (110 mg.) in *NN*-dimethylformamide (5 ml.) were heated under reflux for 24 hr. The product, isolated with ether, was percolated in benzene–light petroleum (b. p. 40—60°) (1 : 1) through alumina (10 g.). Crystallisation at 0° from methanol–pentane (10 : 1) gave cholesta-4 : 6-dien-3-one, pale yellow prisms, m. p. 78°, $\lambda_{max.}$ 284 mμ (log ε 4·36) (Found: C, 84·3; H, 11·2. Calc. for $C_{27}H_{42}O$: C, 84·7; H, 11·1%); the dinitrophenylhydrazone formed dark red needles, m. p. 232°.

(ii) Cholesta-4 : 6-dien-3-one, m. p. 78°, $\lambda_{max.}$ 284 mμ (log ε 4·36) was obtained by heating the ketone (I*a*) with lithium chloride–collidine under reflux for 2 hr. Heating with collidine alone gave impure cholesta-4 : 6-dien-3-one.

[7] Cf. Bremer, Congress Handbook, XIVth Intern. Congr. of Pure and Applied Chem., p. 162.

4-*Bromotestosterone Propionate* (IIb).—(i) Testosterone propionate (1 g.) in ether (20 ml.) and collidine (2 ml.) was treated with bromine in acetic acid (3·0 ml.; 0·98M) at 20—25° for 72 hr. in the dark. Isolation with ether gave an intractable oil which was fractionated by chromatography on alumina (10 g.) in benzene–light petroleum, then crystallised from methanol. 4-*Bromotestosterone propionate* formed needles, m. p. 140—142°, $[\alpha]_D^{25}$ +118° (*c* 0·42), $\lambda_{max.}$ 261 mμ (log ε 4·09) (Found: C, 62·0; H, 7·6; Br, 19·3. $C_{22}H_{31}O_3Br$ requires C, 62·5; H, 7·4; Br, 18·9%).

(ii) Bromination of testosterone propionate (1 g.) in ethylene oxide, followed by percolation of the product in benzene–light petroleum through alumina (10 g.) and crystallisation from methanol, gave 4-bromotestosterone propionate, m. p. 140—142°, $[\alpha]_D^{27}$ +117° (*c* 0·655), $\lambda_{max.}$ 261 mμ (log ε 4·09) (Found: Br, 18·4%), not depressed in admixture with a sample prepared as under (i).

4-*Bromoprogesterone* (IIc).—(i) Bromination of progesterone in the presence of collidine, followed by direct crystallisation of the product, furnished 4-*bromoprogesterone*, needles (from methanol), m. p. 192—193°, $[\alpha]_D^{25}$ +185° (*c* 0·8), $\lambda_{max.}$ 261 mμ (log ε 4·07) (Found: C, 63·5; H, 7·4; Br, 19·5. $C_{21}H_{29}O_2Br$ requires C, 64·1; H, 7·4; Br, 20·3%).

(ii) Bromination of progesterone (1 g.) in ethylene oxide, followed by percolation in benzene–light petroleum through alumina (10 g.), gave 4-*bromoprogesterone*, m. p. 193—193·5°, $[\alpha]_D^{25}$ +185° (*c* 0·80), $\lambda_{max.}$ 261 mμ (log ε 4·07) (Found: Br, 20·0%), not depressed in admixture with a sample prepared as under (i). Bromination in propylene oxide gave nearly identical results.

4-*Bromo*-17α-*hydroxyprogesterone* (IId), prepared by bromination of the ketone (Id) in ethylene oxide, formed a microcrystalline powder, m. p. 176°, $\lambda_{max.}$ 259 mμ (log ε 4·04) (Found: Br, 19·1. $C_{21}H_{29}O_3Br$ requires Br, 19·5%), after crystallisation from acetone–hexane (1 : 1).

4-*Bromo*-11-*oxoprogesterone* (IIe) formed a microcrystalline powder, m. p. 146°, $\lambda_{max.}$ 258—259 mμ (log ε 4·00) (Found: C, 61·7; H, 6·8; Br, 20·0. $C_{21}H_{27}O_3Br$ requires C, 61·9; H, 6·7; Br, 19·6%), after crystallisation from acetone–hexane.

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Chemical Research Laboratories,
The British Drug Houses Ltd., London, N.1. [*Received, September 23rd,* 1955.]

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126. *Chemical Examination of* Wedelia calendulacea. *Part I. Structure of Wedelolactone.*

By T. R. Govindachari, K. Nagarajan, and B. R. Pai.

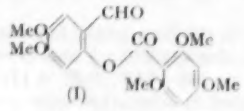
A new lactone, wedelolactone, has been isolated from *Wedelia calendulacea*. Its trimethyl ether is shown to be the lactone of 2-(2-hydroxy-4 : 6-dimethoxyphenyl)-5 : 6-dimethoxybenzofuran-3-carboxylic acid.

From *Wedelia calendulacea* (natural order Compositæ) we have isolated a lactone $C_{16}H_{10}O_7$, named wedelolactone, which contains one methoxyl group, forms a triacetate and a tribenzoate, and has an absorption band at 1707 cm.$^{-1}$ characteristic of an unsaturated δ-lactone. Complete methylation with dimethyl sulphate and potassium carbonate in acetone gave tri-*O*-methylwedelolactone, $C_{19}H_{16}O_7$; on hydrolysis this yielded tri-*O*-methylwedelic acid, $C_{19}H_{18}O_8$, which gave a blue colour with Folin–Denis reagent and was converted back into tri-*O*-methylwedelolactone when heated alone or refluxed with alcoholic hydrogen chloride. The acid with ethereal diazomethane gave methyl tetra-*O*-methylwedelate, $C_{21}H_{22}O_8$, which showed a negative Folin–Denis test and had an ester-carbonyl absorption at 1716 cm.$^{-1}$, indicating its probable aromatic nature. Hydrolysis of this ester with alcoholic potassium hydroxide gave tetra-*O*-methylwedelic acid, $C_{20}H_{20}O_8$, which was readily decarboxylated at 240—260°.

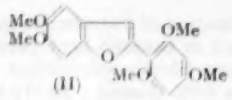
Ozonolysis of the decarboxylation product, $C_{19}H_{20}O_6$, in chloroform gave an ozonide which was decomposed to a crystalline aldehyde, $C_{19}H_{20}O_8$, showing absorption bands at 1675 (aromatic aldehyde) and 1753 cm.$^{-1}$ (phenol ester). Alkaline hydrolysis of the ozonolysis product furnished 6-hydroxyveratraldehyde and 2 : 4 : 6-trimethoxybenzoic

acid. (It may be noted that 6-hydroxyveratraldehyde forms the dimedone derivative with direct elimination of two molecules of water, which seems to be a characteristic of *o*-hydroxybenzaldehydes.[1])

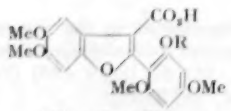
From the above experiments it is clear that the ozonolysis product is 6-(2 : 4 : 6-trimethoxybenzoyloxy)veratraldehyde (I), and that the product, $C_{19}H_{20}O_6$, obtained by



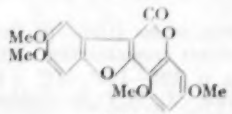
(I)



(II)



(III) : R = Me
(III*a*) : R = H



(IV)

decarboxylation of tetra-*O*-methylwedelic acid is 5 : 6-dimethoxy-2-(2 : 4 : 6-trimethoxyphenyl)benzofuran (II). Tetra- and tri-*O*-methylwedelic acid must be represented by (III) and (III*a*) respectively. Tri-*O*-methylwedelolactone can therefore be assigned structure (IV).

Work is in progress with a view to locating the lone methoxy-group in wedelolactone.

Experimental

Ultraviolet absorption spectra were measured for absolute ethanol solutions with a Beckman Model DUV Spectrophotometer. Analyses are by Mr. S. Selvavinayagam.

Extraction of Wedelia calendulacea.—Fresh green leaves of the plant (3 kg.) were extracted continuously with hot 90% alcohol containing 2% of acetic acid until the extract was no longer coloured. The extract was then concentrated until separation of solid material began. After cooling and removal of a considerable amount of chlorophyll and wax that had separated, the filtrate was concentrated *in vacuo* to 1—1·5 l. and extracted repeatedly with ether until the latter was colourless. The combined ether extracts were washed with water, dried (Na_2SO_4), and evaporated. The residual green solid was washed with a little ether, to give *wedelolactone* (0·5 g. per kg. of fresh leaves). Two crystallisations from methanol gave greenish-yellow needles, m. p. 327—330° (decomp. from 280°) (Found : C, 61·2, 61·6; H, 3·3, 3·2; OMe, 8·5. $C_{16}H_{10}O_7$ requires C, 61·2; H, 3·2; 1OMe, 9·9%). The lactone is sparingly soluble in ether, methanol, ethanol, benzene, and chloroform, but readily soluble in warm pyridine; an alcoholic solution gives a dark green colour with ferric chloride. The *triacetate*, made by use of acetic anhydride in pyridine at 100°, crystallised from acetic acid in needles, m. p. 235—237° (Found : C, 60·3; H, 3·8. $C_{22}H_{16}O_{10}$ requires C, 60·0; H, 3·6%). The *tribenzoate*, prepared by use of benzoyl chloride in alkali, on crystallisation from 2-ethoxyethanol, melted at 267—269° (Found : C, 71·2; H, 3·9. $C_{37}H_{22}O_{10}$ requires C, 70·9; H, 3·5%).

Tri-O-methylwedelolactone.—Wedelolactone (2 g.), potassium carbonate (25 g.), dimethyl sulphate (15 ml.), and dry acetone (100 ml.) were heated at 100° for 8 hr. Acetone was distilled off, and the residue treated with water and filtered. The precipitate was washed with alkali, then with water and with alcohol. Recrystallisation from acetic acid gave colourless needles of *tri-O-methylwedelolactone* (1·9 g.), m. p. 247° (Found : C, 63·7, 63·6; H, 4·8, 4·6; OMe, 33·5. $C_{19}H_{16}O_7$ requires C, 64·0; H, 4·5; 4OMe, 34·8%), recovered unchanged after refluxing with aniline or alcoholic ammonia.

Tri-O-methylwedelic Acid.—Tri-*O*-methylwedelolactone (1·5 g.) was refluxed with alcohol (100 ml.) containing potassium hydroxide (4 g.) for 4 hr. The solvent was removed *in vacuo*. The residue was dissolved in water, the solution filtered from amorphous material, and the filtrate made acidic. The precipitate was washed with water to give *tri-O-methylwedelic acid* (1·5 g.). Crystallisation from alcohol gave colourless needles which lost water at 192° and melted at 237—240° (Found : C, 61·4; H, 4·8. $C_{19}H_{18}O_8$ requires C, 61·0; H, 4·8%); in alcohol a deep orange colour was obtained with ferric chloride.

[1] Horning and Horning, *J. Org. Chem.*, 1946, **11**, 95.

Action of Heat on Tri-O-methylwedelic Acid.—The acid (0·15 g.) was kept at 250—260° for 1 hr. The product was cooled, washed with alkali and then with water, and recrystallised from acetic acid to give needles, m. p. and mixed m. p. with tri-*O*-methylwedelolactone, 246—247°.

Action of Methanolic Hydrogen Chloride on Tri-O-methylwedelic Acid.—The acid (0·2 g.) in methanol (10 ml.) was saturated with dry hydrogen chloride at 0° and then refluxed for 5 hr. The precipitate was filtered off, and washed successively with alkali and water. Crystallisation from acetic acid gave colourless needles, m. p. and mixed m. p. with tri-*O*-methylwedelolactone, 245—246°.

Methyl Tetra-O-methylwedelate.—Tri-*O*-methylwedelic acid (0·9 g.) in ether (50 ml.) and methanol (25 ml.) was left with ethereal diazomethane (from 6 g. of methylnitrosourea) for 24 hr. The solvent was evaporated and the residue washed with sodium hydrogen carbonate solution and then with water. The dried material (0·86 g.) was digested with boiling methanol (50 ml.) and filtered. Concentration to 25 ml. and cooling gave *methyl tetra-O-methylwedelate* (0·55 g.), m. p. 166—167°, $\lambda_{max.}$ 310 mμ (log ε 4·21) (Found: C, 63·2; H, 5·8; OMe, 45·0. $C_{21}H_{28}O_8$ requires C, 62·7; H, 5·5; 6OMe, 46·3%), showing no colour with ferric chloride. The ester was unaffected by 2 : 4-dinitrophenylhydrazine, acetic anhydride in pyridine, potassium permanganate in acetone, or hydrogen at 60 lb./sq. in. in the presence of Adams catalyst.

The methanol-insoluble material from this esterification, on crystallisation from acetic acid, gave tri-*O*-methylwedelolactone (0·11 g.), m. p. 247°.

Tetra-O-methylwedelic Acid.—Methyl tetra-*O*-methylwedelate (1·03 g.) was refluxed with potassium hydroxide (3·4 g.) in water (10 ml.) and alcohol (10 ml.) for 4 hr. Alcohol was distilled off, and the solution diluted with water and filtered. Acidification and crystallisation of the precipitate from alcoholic acetic acid gave *tetra-O-methylwedelic acid* (0·6 g.), m. p. 225—228° (gas evolution) (Found: C, 62·3; H, 5·6%; equiv., 382. $C_{20}H_{28}O_8$ requires C, 61·9; H, 5·2%; equiv., 388).

A suspension of the acid (0·1 g.) in methanol (25 ml.) and ether (50 ml.) was left with ethereal diazomethane (from 2·5 g. of methylnitrosourea) for 24 hr. and then the solvent was evaporated. The residue was washed with alkali and then with water to give the ester (0·1 g.), m. p. and mixed m. p. with methyl tetra-*O*-methylwedelate, 165—167°.

Decarboxylation of Tetra-O-methylwedelic Acid.—The acid (0·5 g.) was heated at 240—260° for 2 hr. and the product sublimed at 150—160°/0·01 mm. The sublimate was ground with alkali, filtered, and washed with water, to give *5 : 6-dimethoxy-2-(2 : 4 : 6-trimethoxyphenyl)-benzofuran* (0·4 g.), m. p. 143—145°. Recrystallisation from ether gave colourless needles (0·35 g.), m. p. 145°, $\lambda_{max.}$ 275 (log ε 4·15) and 310 mμ (log ε 4·35) (Found: C, 66·5, 66·6, 66·7; H, 5·8, 5·6, 6·0. $C_{19}H_{20}O_6$ requires C, 66·3; H, 5·8%), unaffected by acetic anhydride, hydroxylamine, potassium permanganate in acetone, or hydrogen as above.

Ozonolysis of 5 : 6-Dimethoxy-2-(2 : 4 : 6-trimethoxyphenyl)benzofuran.—A solution of the compound (1·2 g.) in chloroform (50 ml.) was treated with a 50% excess of ozone during 10 hr. at 0°. The solvent was then removed *in vacuo* at 30° and the ozonide refluxed for 1 hr. with water (110 ml.), zinc dust (0·35 g.), and a few crystals each of quinol and silver nitrate. The mixture was shaken with chloroform (50 ml.) and filtered. The filtrate was made acidic, the chloroform layer separated, and the aqueous layer extracted with more of the solvent. The combined extracts were washed successively with sodium hydrogen carbonate solution, dilute sodium hydroxide, and water, and then dried (Na_2SO_4). Evaporation and recrystallisation of the residue from methanol gave colourless needles of *6-(2 : 4 : 6-trimethoxybenzoyloxy)veratraldehyde* (0·52 g.), m. p. 159—160°, $\lambda_{max.}$ 272 (log ε 4·27) and 318 mμ (log ε 3·94) (Found: 61·0, 61·1; H, 5·3, 5·3. $C_{19}H_{20}O_8$ requires C, 60·6; H, 5·3%), which afforded a *2 : 4-dinitrophenylhydrazone*, orange needles (from acetic acid), 280—282° (decomp.) (Found: C, 53·8, 54·0; H, 4·3, 4·6; N, 10·0, 10·1. $C_{25}H_{24}O_{11}N_4$ requires C, 54·0; H, 4·3; N, 10·1%), *semicarbazone* (from dilute acetic acid), m. p. 213—215° (decomp.) (Found: C, 56·0; H, 5·7; N, 9·7. $C_{20}H_{23}O_8N_3$ requires C, 55·4; H, 5·3; N, 9·7%), and *dimedone derivative*, cubes (from dilute methanol), m. p. 171° (Found: C, 65·4; H, 6·8. $C_{35}H_{42}O_{11}$ requires C, 65·8; H, 6·6%).

The bicarbonate and alkaline extracts yielded, on acidification, small amounts of an acid and a phenol respectively, which were not characterised.

Hydrolysis of 6-(2 : 4 : 6-Trimethoxybenzoyloxy)veratraldehyde.—The ester (0·52 g.) was left with potassium hydroxide (2·7 g.), dissolved in alcohol (25 ml.), at 30° for 3 hr. with frequent shaking. The solvent was then removed at 30° *in vacuo* and water added to the residue. The clear yellow solution was saturated with carbon dioxide and extracted repeatedly with ether. The dried ether layer on evaporation gave 6-hydroxyveratraldehyde (0·25 g.), crystallising from

light petroleum (b. p. 40—60°) as pale yellow needles, m. p. 105° alone or mixed with a synthetic specimen [2] (Found : C, 59·8, 59·5; H, 5·4, 5·1. Calc. for $C_9H_{10}O_4$: C, 59·3; H, 5·5%), giving a dark green colour with ferric chloride, changing to brown on dilution, a *phenylhydrazone*, pale yellow plates (from light petroleum), m. p. 139—140° (Found : C, 66·3; H, 5·4. $C_{15}H_{16}O_3N_2$ requires C, 66·2; H, 5·9%), dimedone derivative (from dilute methanol), colourless plates, m. p. and mixed m. p. 191—193° (Found : C, 70·0, 70·1; H, 6·6, 6·8. Calc. for $C_9H_{10}O_4 + C_{16}H_{24}O_4 - 2H_2O$, *i.e.*, $C_{25}H_{30}O_6$: C, 70·4; H, 7·0%), methyl ether,[3] needles (from water), m. p. 113—114° after drying at 80°/5 mm., and benzoate (from light petroelum), colourless needles passing into pale yellow cubes, m. p. 100°.

The bicarbonate extract from the hydrolysis was acidified and extracted thoroughly with ether. Evaporation of the ether yielded a solid (0·21 g.), crystallising from benzene in colourless needles, m. p. 143° (decomp.) alone or mixed with synthetic 2 : 4 : 6-trimethoxybenzoic acid [4] (Found : C, 56·8, 56·5; H, 5·9, 5·7. Calc. for $C_{10}H_{12}O_5$: C, 56·6; H, 5·7%).

Attempted Demethylation of Wedelolactone.—The lactone (0·25 g.) and 48% hydrobromic acid (10 ml.) were refluxed for 1 hr., then diluted with water and filtered. Crystallisation from dilute alcohol yielded only *wedelic acid*, m. p. 333° (decomp.) (Found : C, 57·9; H, 3·7; OMe, 10·0. $C_{14}H_{12}O_8$ requires C, 57·8; H, 3·6; 1OMe, 9·3%).

Action of Hydrogen Peroxide on Wedelolactone.—The lactone (0·5 g.), dissolved in 5% potassium hydroxide solution (35 ml.), was left with hydrogen peroxide (100 ml.; 25-vol.) at 30° for 24 hr. The initially red solution soon became colourless. It was then heated at 60° for 2 hr., acidified, and extracted repeatedly with ether. The contents of the ether layer were separated into neutral (0·1 g.), phenolic (0·06 g.), and acidic (0·19 g.) fractions. The acidic part was sublimed *in vacuo* and the sublimate converted into the *p*-bromophenacyl ester, needles (from ethyl acetate), m. p. 209—211°, in too small a quantity for analysis. The neutral and the phenolic portion also could not be characterised.

We thank Dr. R. Subramaniam, Physician and Professor of Therapeutics, Madras Medical College, at whose suggestion this investigation was commenced, the C.S.I.R., Government of India, for a grant which defrayed the expenses and who awarded a research assistantship (to K. N.), and also Dr. E. Schlittler for infrared absorption data.

PRESIDENCY COLLEGE, MADRAS. [*Received, September 27th*, 1955.]

[2] Arnold and Bordwell, *J. Amer. Chem. Soc.*, 1942, **64**, 2984.
[3] Head and Robertson, *J.*, 1930, 2434.
[4] Holmes, White, and Wilson, *J.*, 1950, 2810.

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127. *An Examination of the Rutaceae of Hong Kong. Part I. Flavonoid Glycosides from* Zanthoxylum *Species and the Occurrence of Optically Active Hesperetin.*

By H. R. ARTHUR, (MISS) W. H. HUI, and (in part) C. N. MA.

Hesperidin and diosmin occur in barks of *Zanthoxylum* species of Hong Kong. Hydrolysis of hesperidin yields a mixture of (±)- and (−)-hesperetin from which the pure constituents have been isolated. These compounds have been characterised, and (−)-hesperetin has been racemised. Hesperetin has been converted into diosmetin by the use of *N*-bromosuccinimide.

From this work it is concluded that hesperidin is a β-7-rutinoside of (−)-hesperetin.

HESPERIDIN, which occurs in *Citrus* species, was first reported by Hilger.[1] Zemplén and Bognár [2] showed that it is a β-7-rutinoside of hesperetin, a flavanone synthesised by Shinoda and Kawagoye.[3] Diosmin, which occurs in hyssop plants, was isolated by Oesterle and Wander ;[4] its structure was elucidated by Zemplén and Bognár [5] who converted hesperidin

[1] Hilger, *Ber.*, 1876, **9**, 26.
[2] Zemplén and Bognár, *Ber.*, 1943, **76**, 773.
[3] Shinoda and Kawagoye, *J. Pharm. Soc. Japan*, 1928, **48**, 938.
[4] Oesterle and Wander, *Helv. Chim. Acta*, 1925, **8**, 519.
[5] Zemplén and Bognár, *Ber.*, 1943, **76**, 452.

into diosmin by a modified Kostanecki procedure; it is the glycoside of the flavanone diosmetin which was synthesised by Lovecy, Robinson, and Sugasawa.[6]

We report here that hesperidin and diosmin occur in the bark of *Zanthoxylum avicennae*, that hesperidin occurs in the bark of *Z. cuspidatum*, and that diosmin occurs in the root bark of *Z. nitidum*; the bark of the last species contains neither glycoside. The three plants are indigenous to Hong Kong.

Hydrolysis of hesperidin (from both *Z. avicennae* and *Z. cuspidatum*) with either dilute sulphuric acid or sulphuric acid in ethylene glycol yields an optically active mixture of (±)- and (−)-hesperetin from which the two have been separated by fractional recrystallisation. Both have been characterised by conversion into derivatives, and (−)hesperetin has been racemised.

Each of two authentic samples of hesperidin, kindly supplied by Professor T. R. Seshadri and Dr. J. T. Pinhey, on hydrolysis also yields a mixture of (±)- and (−)-hesperetin. Since the m. p.s for hesperetin and its derivatives stated by previous workers do not correspond throughout exactly with those of either (±)-hesperetin and its derivatives or (−)-hesperetin and its derivatives which we have obtained, we believe that much of the previous work on hesperetin has been carried out on optical mixtures, although workers who hydrolysed hesperidin under pressure in an autoclave probably obtained (±)-hesperetin. Also since recrystallisation of the optical mixture leads to a product richer in (±)-hesperetin, some previous workers may have obtained a product rich in racemate. Nevertheless no rotations have previously been recorded for hesperetin; and we describe here for the first time the preparation of both (±)- and (−)-hesperetin and their derivatives.

We conclude that hesperidin is a β-7-rutinoside of (−)-hesperetin.

Although very many naturally occurring flavanones have been reported, optically active forms are exceedingly rare. Fujise[7] isolated (−)-matteucinol and (−)-demethoxymatteucinol. Arthur[8] reported the occurrence of (−)-farrerol, Hillis[9] that of (+)-dihydrokaempferol, and Erdtman[10] that of (−)-dihydrochrysin. Whilst matteucinol, demethoxymatteucinol, and farrerol exhibit the structural regularity of methyl groups in the 6- and the 8-position, the other two and hesperetin do not. With the exception of dihydrokaempferol all naturally occurring optically active flavanones are lævorotatory.

We have converted hesperetin into diosmetin by the method of Seshadri and Bannerjee[11] and Lorette *et al.*,[12] using *N*-bromosuccinimide. This has been done previously only by a modified Kostanecki procedure.

Previous work on *Zanthoxylum* species has been surveyed by King, Housley, and King.[13]

Experimental

Analyses are by Dr. Zimmermann, Melbourne.

Zanthoxylum avicennae.—(a) *Isolation of hesperidin and diosmin.* Dried bark (400 g.) was extracted with boiling methanol (8 l.). The extract was reduced to 1 l. Next morning a greenish-brown semi-crystalline solid (2·4 g.) was collected and the filtrate was evaporated to 400 ml. The pale brown crystals (1·5 g.) which separated were collected.

The first crop was extracted with light petroleum (b. p. 60—80°) and then with methanol. The light brown crystalline residue (1·4 g.) was recrystallised 4 times from 50% aqueous pyridine (charcoal). Nearly colourless fine needles of diosmin hydrate, m. p. 280° (decomp.; vac.) (Found: C, 53·4; H, 5·4; OMe, 5·0. Calc. for $C_{28}H_{32}O_{15}.H_2O$: C, 53·7; H, 5·4; 1OMe, 5·0%), were obtained.

The second crop treated in a similar manner yielded mainly hesperidin hydrate as almost

[6] Lovecy, Robinson, and Sugasawa, *J.*, 1930, 817.
[7] Fujise, *Sci. Papers Inst. Phys. Chem. Res. (Tokyo)*, 1929, **11**, 111.
[8] Arthur, *J.*, 1955, 3740.
[9] Hillis, *Austral. J. Sci. Res.*, 1952, **5**, *A*, 376.
[10] Erdtman, *Svensk Papperstidning*, 1943, **46**, 226.
[11] Bannerjee and Seshadri, *Proc. Indian Acad. Sci.*, 1952, **36**, *A*, 138.
[12] Lorette, Gage, and Wander, *J. Org. Chem.*, 1951, **16**, 930.
[13] King, Housley, and King, *J.*, 1954, 1392.

colourless fine needles, m. p. 260° (decomp.; vac.), $[\alpha]_D^{27}$ −88·2° (*c* 1·24 in pyridine) (Found: C, 53·9; H, 6·0; OMe, 4·8. Calc. for $C_{28}H_{34}O_{15}.H_2O$: C, 53·5; H, 5·7; 1OMe, 4·9%), and diosmin hydrate which was less soluble in aqueous pyridine.

(b) *Diosmin.* Diosmin (5 g.) was treated with acetic anhydride (50 ml.) and pyridine (25 ml.) at room temperature for 4 days. After the product had been collected from water, it was recrystallised from ethanol, and then boiled for 2 hr. with sulphuric acid (5 ml.) in ethanol (95 ml.). The hydrolysis mixture was poured into water; the product crystallised from ethanol in fine yellow needles of diosmetin, m. p. 253—254·5° (Found: C, 63·5; H, 4·3; OMe, 10·3. Calc. for $C_{16}H_{12}O_6$: C, 64·0; H, 4·0; 1OMe, 10·3%). The triacetate formed colourless needles, m. p. 189—191° (Found: C, 61·6; H, 4·5; Ac, 30·3. Calc. for $C_{22}H_{18}O_9$: C, 62·0; H, 4·2; 3Ac, 30·3%). Both compounds gave a red colour with magnesium and hydrochloric acid in methanol. Diosmetin was also prepared from the hydrolysis of diosmin in ethylene glycol by using the method which we applied for the hydrolysis of hesperidin.

(c) *Hesperidin.* Hesperidin (10 g.) was boiled under reflux in 6% sodium hydroxide solution (200 ml.) for 2 hr. The solution was acidified, and then extracted with ether (2 l.). Crystallisation from aqueous ethanol of the residue (2·2 g.) obtained after removal of ether gave colourless needles of *iso*ferulic acid, m. p. 228—229° (Found: C, 62·1; H, 5·4; OMe, 15·9. Calc. for $C_{10}H_{10}O_4$: C, 61·8; H, 5·2; 1OMe, 16·0%) [acetate, m. p. 204—205° (Found: C, 61·5; H, 5·3. Calc. for $C_{12}H_{12}O_5$: C, 61·0; H, 5·1%)]. *iso*Ferulic acid gave a red-brown colour with ferric chloride solution. Hesperidin (5 g.) was treated at room temperature with acetic anhydride and pyridine. The product (5·2 g.), collected from water, was recrystallised from ethanol. Colourless needles of the acetate, m. p. 176—179° (Found: C, 55·7; H, 5·6; OMe, 3·4; Ac, 34·4%; *M*, 862. Calc. for $C_{44}H_{50}O_{23}$: C, 55·8; H, 5·3; 1OMe, 3·3; 8Ac, 36·4%; *M*, 946), separated.

Previous workers report difficulty in hydrolysing hesperidin but Gupta, Narasimhachari, and Seshadri [11] report an 80% yield of hesperetin from hydrolysis of hesperidin acetate. We have obtained a nearly quantitative yield of hesperetin in a smooth hydrolysis of the glycoside as follows: Hesperidin (5 g.) and ethylene glycol (100 ml.) containing sulphuric acid (5 ml.) were heated on the water-bath for 40 min. The clear yellow solution obtained was poured into water (200 ml.). The product (1·8 g.) was collected and recrystallised from ethanol. Leaf-shaped crystals of a mixture of (±)-hesperetin and (−)-hesperetin, m. p. 224—226° (after becoming misty at 212°), $[\alpha]_D^{26}$ −16·9° (*c* 1·42 in EtOH) (Found: C, 63·8; H, 4·8. Calc. for $C_{16}H_{14}O_6$: C, 63·6; H, 4·6%), separated.

Hesperidin (4 g.) was also hydrolysed by boiling its suspension in dilute sulphuric acid (50 ml.) for 20 hr. A mixture of (±)- and (−)-hesperetin was obtained from the insoluble residue, and glucose and rhamnose were isolated and separated as their osazones from the filtrate.

Authentic hesperidin obtained from other sources gave similarly on hydrolysis the optical mixture.

(d) *Separation of* (±)- *and* (−)-*hesperetin.* The mixture (20 g.) was fractionally recrystallised from ethanol, by a triangular scheme. The less soluble fraction (2·2 g.), obtained as hexagonal prisms, was (±)-*hesperetin*, m. p. 226—228°, $[\alpha]_D^{27}$ 0·0° (*c* 1·56 in EtOH) (Found: C, 64·1; H, 5·0; OMe, 10·3%; *M*, 347. $C_{16}H_{14}O_6$ requires C, 63·6; H, 4·6; 1OMe, 10·3%; *M*, 302). The more soluble fraction, obtained as triangular plates, was (−)-*hesperetin* (2·5 g.), m. p. 216—218°, $[\alpha]_D^{27}$ −37·6° (*c* 1·80 in EtOH) (Found: C, 63·8; H, 4·8; OMe, 10·3%; *M*, 346).

(e) *Derivatives of* (±)-*hesperetin.* (±)-Hesperetin (0·6 g.) was converted by means of diazomethane into the 7:4′-dimethyl ether (0·3 g.), m. p. 132—133° (Found: C, 65·3; H, 5·6; OMe, 27·8. Calc. for $C_{18}H_{18}O_6$: C, 65·5; H, 5·5; 3OMe, 28·2%) (Waung [12] gives m. p. 133—136° and 153—155°; Haley and Bassin [13] give m. p. 153·2—154·8°). (±)-Hesperetin (0·4 g.) was heated in aqueous ethanol with sodium acetate (0·5 g.) and hydroxylamine hydrochloride (0·5 g.) for 18 hr. The product, on recrystallisation from aqueous ethanol, yielded fine needles (0·34 g.) of the oxime, m. p. 227—228° (decomp.) (Found: C, 60·8; H, 4·7; N, 4·3. Calc. for $C_{16}H_{15}O_6N$: C, 60·6; H, 4·7; N, 4·4%). (Shinoda and Kawagoye [3] give m. p. 229—230°.) (±)-Hesperetin (1·2 g.) was acetylated by the method of Bannerjee and Seshadri,[11] using ice-cold pyridine (5 ml.) and acetyl chloride (2 ml.). The product crystallised from methanol in colourless needles (0·95 g.) of the triacetate, m. p. 139—141° (Found: C, 61·9; H, 4·8; Ac, 29·0. Calc.

[11] Gupta, Narasimhachari, and Seshadri, *J. Sci. Ind. Res. India*, 1953, **12**, *B*, 229.
[12] Waung, *J. Pharm. Soc. Japan*, 1940, **60**, 420.
[13] Haley and Bassin, *J. Amer. Pharm. Assoc.*, 1951, **40**, 111.

for $C_{22}H_{20}O_9$: C, 61·7; H, 4·7; 3Ac, 30·1%) (Asahina, Shinoda, and Inubuse [17] give m. p. 80—82°; and Waung [15] gives m. p.s 127—129° and 165—167°).

(f) *Derivatives of* (−)-*hesperetin.* These were prepared as described for those of (±)-hesperetin and were found to be: 7 : 4′-*dimethyl ether*, m. p. 149—151°, $[\alpha]_D^{28}$ −35·6° (*c* 1·04 in $CHCl_3$) (Found : C, 65·7; H, 5·6; OMe, 27·8%); *oxime*, m. p. 219—220° (decomp.), $[\alpha]_D^{27}$ −16·1° (*c* 0·40 in EtOH) (Found : C, 60·9; H, 4·8; N, 4·3%); *triacetate*, m. p. 130—132°, $[\alpha]_D^{26}$ +21·1° (*c* 1·28 in $CHCl_3$) (Found : C, 62·0; H, 4·9; Ac, 29·8%).

(±)- and (−)-Hesperetin and their derivatives gave a bright red solution with magnesium and hydrochloric acid in methanol.

(g) *Racemisation of* (−)-*hesperetin.* A solution of (−)-hesperetin (0·4 g.) in ethylene glycol (5 ml.) was heated in a sealed tube at 250—260° for 2 hr. The reddish-brown solution was then poured into water, and the product, collected as usual, deposited (±)-hesperetin (0·1 g.), m. p. and mixed m. p. 225—227°, $[\alpha]_D^{26}$ 0·0° (*c* 0·50 in EtOH), after recrystallisation from ethanol. Solutions of (−)-hesperetin in ethanolic sodium hydroxide or ethanolic hydrochloric acid did not racemise during 3 days.

(h) *Conversion of hesperetin into diosmetin.* A solution of hesperetin triacetate (0·9 g.), *N*-bromosuccinimide (0·45 g.), and benzoyl peroxide (0·05 g.) was heated on a steam-bath for 1 hr., then more *N*-bromosuccinimide (0·3 g.) was added. The solution was boiled for another 2 hr. Next morning succinimide was removed and the filtrate was evaporated to dryness. The residue was washed with hot water, and then recrystallised 4 times from ethanol. Pale yellow crystals of diosmetin (0·08 g.), m. p. and mixed m. p. 250—253°, were obtained.

Zanthoxylum cuspidatum.—*Isolation of hesperidin.* Dried bark (400 g.) was extracted as stated for *Zanthoxylum avicennae*. After the extract had been reduced to 1 l., fine needles (1·4 g.) were formed on cooling. These were collected and then the filtrate was concentrated to 250 ml. A second crop of crystals (0·5 g.) which was deposited was combined with the first. Purification of this material yielded hesperidin hydrate, m. p. and mixed m. p. 260° (Found : C, 53·9; H, 5·9; OMe, 5·0. Calc. for $C_{28}H_{34}O_{15}.H_2O$: C, 53·5; H, 5·7; 1OMe, 4·9%), which was characterised by conversion into hesperetin (also optically active).

Zanthoxylum nitidum [with C. N. Ma].—(a) *Isolation of diosmin from root bark.* Milled root bark (31 kg.) was extracted with hot methanol (170 l.) for 25 hr. The extract was concentrated to 5 l. and allowed to cool. A mixture of yellow crystalline alkaloidal material (40 g.) with properties similar to those of the chelidonine group of alkaloids was collected for further investigation, and the mother-liquor was evaporated to dryness under reduced pressure. The residue was extracted with light petroleum (b. p. 60—80°), and that portion of it which was insoluble in petroleum was dried and dissolved in methanol (200 ml.). Next week fine pale brown crystals (2 g.) were collected. Crystallisation of these from aqueous pyridine gave diosmin hydrate, m. p. and mixed m. p. 283° (decomp.; vac.) (Found : C, 54·2; H, 5·9; OMe, 5·1. Calc. for $C_{28}H_{32}O_{15}.H_2O$: C, 53·7; H, 5·4; OMe, 5·0%). Insufficient material was obtained for further characterisation.

(b) *Extraction of bark.* Dried bark (400 g.) was extracted as stated for *Zanthoxylum avicennae*. Neither hesperidin nor diosmin was found in the extract.

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University of Hong Kong, Hong Kong. [*Received, October 3rd,* 1955.]

[17] Asahina, Shinoda, and Inubuse, *J. Pharm. Soc. Japan*, 1928, **48**, 207.

128. *The Structure of Bouchardat's Dichlorodideoxydulcitol and the Synthesis of* 1 : 6-*Diamino*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol.*

By K. Butler and W. A. W. Cummings.

The structure of a dichlorodideoxydulcitol prepared by Bouchardat [1] is proved by synthesis. The preparation of 1 : 6-diamino-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol, together with characteristic derivatives, is described.

Diamines derived from carbohydrate sources may offer useful monomers for the preparation of polyamides. To obviate cross-linking during the polymerisation process it is necessary to protect the hydroxyl groups, and methylene bridges have been used for this purpose. Further, for the preparation of linear unbranched polymers it is essential that the amino-groups be attached to terminal carbon atoms of the monomer chain. For example, Haworth, Heath, and Wiggins [2] have prepared a fibre-forming polymer from 1 : 6-diamino-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenemannitol and adipic acid.

In the present work the sugar alcohol selected was dulcitol, and a possible route to the required diamine is :

Dulcitol ⟶ 1 : 6-Dichloro-1 : 6-dideoxydulcitol

↓

1 : 6-Dichloro-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol

1 : 6-Diamino-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol (I)

A dichlorodideoxydulcitol first described by Bouchardat [1] was considered by Hamamura [3] to be 1 : 6-disubstituted. Hamamura found that it gave monochloroacetaldehyde (identified as its 2 : 4-dinitrophenylhydrazone) when oxidised with lead tetra-acetate in benzene. With lead tetra-acetate in acetic acid he obtained a compound which he believed to be 2-hydroxy-3 : 4-epoxybutyraldehyde, but which was being further examined. Although this evidence suggests that Bouchardat's compound was 1 : 6-dichloro-1 : 6-dideoxydulcitol, it was necessary to establish the structure unequivocally before proceeding with the amination experiments.

The following synthetic route provides an unambiguous proof of the position of the chlorine atoms.

1 : 6-Di-*O*-benzoyldulcitol ⟶ 1 : 6-Di-*O*-benzoyl-2 : 4-3 : 5-di-*O*-methylenedulcitol

↓

1 : 6-Dichloro-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylene- (III) ⟵ 2 : 4-3 : 5-Di-*O*-methylenedulcitol (II)
dulcitol

↑ ↑

Bouchardat's dichlorodideoxydulcitol Dimethyl di-*O*-methylenemucate

1 : 6-Di-*O*-benzoyldulcitol (structure proved by Hann, Maclay, and Hudson [4]) on treatment with paraformaldehyde and concentrated sulphuric acid gave 1 : 6-di-*O*-benzoyl-2 : 4-3 : 5-di-*O*-methylenedulcitol. Removal of the benzoyl groups with a catalytic amount of sodium methoxide gave 2 : 4-3 : 5-di-*O*-methylenedulcitol (II), also formed by the reduction of dimethyl di-*O*-methylenemucate [5] with lithium aluminium hydride. The latter

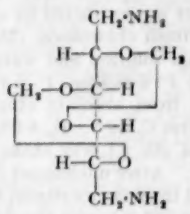
[1] Bouchardat, *Ann. Chim. Phys.*, 1872, **27**, 174.
[2] Haworth, Heath, and Wiggins, *J.*, 1944, 155.
[3] Hamamura, *Bull. Agric. Chem. Soc. Japan*, 1942, **18**, 54.
[4] Hann, Maclay, and Hudson, *J. Amer. Chem. Soc.*, 1939, **61**, 2432.
[5] Personal communication from Prof. M. Stacey.

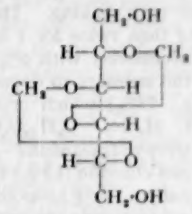
experiment provided an independent confirmation that the primary hydroxyl groups were unsubstituted. Finally, chlorination of the di-*O*-methylene compound, with thionyl chloride in pyridine, yielded 1 : 6-dichloro-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol (III).

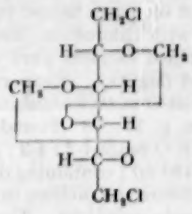
Interaction of Bouchardat's dichlorodideoxydulcitol with paraformaldehyde and concentrated sulphuric acid gave a di-*O*-methylene derivative identical with the product (III). Bouchardat's compound must therefore be 1 : 6-dichloro-1 : 6-dideoxydulcitol.

The orientation of the methylene groups has not been proved, but from the rules deduced by Barker, Bourne, and Whiffen [6] they probably bridge positions 2 : 4 and 3 : 5.

Treatment of the dichloride (III) with a large excess of 30% aqueous ammonia solution in an autoclave gave an amine hydrochloride, from which 1 : 6-diamino-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol (I) was isolated by treatment with excess of barium


(I)


(II)


(III)

hydroxide. A yield of 60% of distilled diamine was obtained. It formed a crystalline dihydrochloride and dipicrate. If heating of the dichloro-compound and ammonia was continued for too long, a spongy halogen-free compound was produced (probably a cross-linked polyamine), and the yield of diamine was reduced. After 5 days' heating, for example, 40% of the weight of starting material had been converted into the polymer, and the yield of amine was only 20%.

The diamine was also synthesised by an alternative route in which 1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylene-1 : 6-diphthalimidodulcitol was the intermediate, but the overall yield was lower. The diphthalimido-compound was prepared by heating together the dichloride (III) and potassium phthalimide. When glycerol was used as the reaction medium a low yield (25%) was obtained, but in *NN*-dimethylformamide the yield was 85%. Hydrolysis of the diphthalimido-compound by means of hydrazine [7] gave the diamine, but in low yield. When condensed with phthalic anhydride this gave a 1 : 6-diphthalimido-derivative identical with that obtained from dichlorodimethylenedulcitol and potassium phthalimide.

Other routes to 1 : 6-diamino-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol were explored, but, as in each case the yields in the initial stages were low, none was pursued to completion. Three methods were considered : (*a*) conversion of mucic acid into 2 : 4-3 : 5-di-*O*-methylenemucamide [8] (overall yield about 50%) which on interaction with thionyl chloride gave 2 : 4-3 : 5-di-*O*-methylenemuconitrile (19%) ; (*b*) if dulcitol could be converted into 1 : 6-di-*O*-benzoyldulcitol in high yield, the method used to prove the structure of 1 : 6-dichloro-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol might afford a useful synthetic route : the yield, however, was only 11% ; in (*c*), dulcitol was converted into 1 : 4-3 : 6-di-*O*-methylenedulcitol [9] which, unlike *iso*propylidene derivatives,[4] did not rearrange on benzoylation in the presence of quinoline to give the required 1 : 6-di-*O*-benzoyl-2 : 4-3 : 5-di-*O*-methylenedulcitol. Instead, 2 : 5-di-*O*-benzoyl-1 : 4-3 : 6-di-*O*-methylenedulcitol was formed.

[6] Barker, Bourne, and Whiffen, *J.*, 1952, 3865.
[7] Ing and Manske, *J.*, 1926, 2348.
[8] Butler and Lawrance, unpublished work.
[9] Weber and Tollens, *Ber.*, 1897, **30**, 2511 ; *Annalen*, 1898, **299**, 318.

Experimental

Bouchardat's Dichlorodideoxydulcitol.—Dulcitol (120 g.) was dissolved in fuming hydrochloric acid (*d* 1·19; 1200 ml.) and sealed off in six glass tubes. These were enclosed in screw-cap iron tubes and heated in an air-oven for 48 hr. at 100°. Only a slight pressure was noticed when the tubes were opened. The brown solution produced was filtered and cooled to 0° for 24 hr., giving yellow-brown crystals of dichlorodideoxydulcitol (27·25 g.), m. p. 183—184° (decomp.). Evaporation of the mother-liquors to about 900 ml. at <50° under diminished pressure gave a further 8·65 g., m. p. 183—185° (decomp.) (total yield 24%). Evaporation to dryness left a residue (77·1 g.) which was dissolved in fuming hydrochloric acid (770 ml.) and sealed up as before. The solution was heated to 100° during 7 hr. and then maintained at 100° for 48 hr. Isolation by the foregoing procedure gave a further batch of dichlorodideoxydulcitol (16·5 g., 10%), m. p. 182—183° (decomp.) (Found: C, 32·8; H, 5·3; Cl, 31·6. Calc. for $C_6H_{12}O_4Cl_2$: C, 32·9; H, 5·5; Cl, 32·4%).

1 : 6-*Dichloro*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol.*—Dichlorodideoxydulcitol (23 g.) was intimately mixed with paraformaldehyde (23 g.), concentrated sulphuric acid (15 ml.) added, and the paste heated to about 60° with shaking. The product was extracted by shaking for 3 hr. with chloroform (250 ml.) and then twice for 1 hr. with fresh chloroform (250 ml.). The combined extracts were washed successively with 5% ammonia solution and water, and then dried ($MgSO_4$). Evaporation of the extracts to dryness gave 1 : 6-*dichloro*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol* (19·2 g., 76%) which crystallised from absolute ethanol as needles, m. p. 77—78° (Found: C, 39·3; H, 4·8. $C_8H_{12}O_4Cl_2$ requires C, 39·5; H, 4·9%).

1 : 6-*Di*-O-*benzoyl*-2 : 4-3 : 5-*di*-O-iso*propylidenedulcitol.*—Dulcitol (25 g.) was shaken with acetone (490 ml.) containing dry hydrogen chloride (12 g.) for 24 hr. After unchanged dulcitol had been filtered off, sodium carbonate (anhyd.; 50 g.) was added, and the mixture stirred for 3 hr. and set aside overnight. The filtered solution was concentrated to 140 ml. and the insoluble product collected. This mixture of di-*O*-*iso*propylidenedulcitols (21·5 g.) was shaken with quinoline (23·2 g.) and benzoyl chloride (23·2 g.) and then heated at 100° for 6 hr. Excess of benzoyl chloride was removed by addition of ethanol (250 ml.) and then by heating for 30 min. at 100°. After cooling of the reactants, the solid was collected, washed with ethanol, and dried, giving a colourless powder (26 g., 65%), m. p. 182—183°, which crystallised from carbon tetrachloride as irregular prisms, m. p. 185—187° (lit., 185—186°) (Found: C, 66·0; H, 6·3. Calc. for $C_{26}H_{30}O_6$: C, 66·4; H, 6·4%).

1 : 6-*Di*-O-*benzoyldulcitol.*—1 : 6-Di-*O*-benzoyl-2 : 4-3 : 5-di-*O*-*iso*propylidenedulcitol (13 g.) was heated with 80% acetic acid (300 ml.) for 45 min. On cooling, 1 : 6-di-*O*-benzoyldulcitol crystallised as plates (10 g., 100%), m. p. 205—208°. Recrystallisation from acetic acid afforded the pure compound, m. p. 209—210° [lit., 209° (corr.)] (Found: C, 61·5; H, 5·4. Calc. for $C_{20}H_{22}O_8$: C, 61·5; H, 5·6%).

1 : 6-*Di*-O-*benzoyl*-2 : 4-3 : 5-*di*-O-*methylenedulcitol.*—1 : 6-Di-*O*-benzoyldulcitol (5 g.), paraformaldehyde (5 g.), and concentrated sulphuric acid (3·75 ml.) were treated in a similar manner to that described for 1 : 6-dichloro-1 : 6-dideoxy-2 : 4-3 : 5-di-*O*-methylenedulcitol. Three crystallisations of the crude product from absolute ethanol gave 1 : 6-*di*-O-*benzoyl*-2 : 4-3 : 5-*di*-O-*methylenedulcitol* (2·75 g., 52%) as needles, m. p. 109·5—110·5° (Found: C, 64·0; H, 5·2. $C_{32}H_{38}O_8$ requires C, 63·8; H, 5·3%).

2 : 4-3 : 5-*Di*-O-*methylenedulcitol.*—To a solution of 1 : 6-di-*O*-benzoyl-2 : 4-3 : 5-di-*O*-methylenedulcitol (2 g.) in chloroform (50 ml.) at 0°, sodium methoxide solution (0·1N; 5 ml.) was added and the mixture set aside overnight. After evaporation of the solvent and removal of methyl benzoate by ether-extraction, 2 : 4-3 : 5-*di*-O-*methylenedulcitol* remained, which crystallised from absolute ethanol as needles (0·6 g., 66%), m. p. 104—104·5° (Found: C, 46·3; H, 6·7. $C_8H_{14}O_6$ requires C, 46·6; H, 6·8%).

Reduction of Dimethyl Di-O-*methylenemucate.*—The ester (13·1 g.), contained in a Soxhlet thimble, was added during 24 hr. to a suspension of lithium aluminium hydride (5 g.) in boiling ether (400 ml.). Water (150 ml.) and then 10% sulphuric acid (150 ml.) were gradually added and the ether layer was removed. The aqueous layer was almost neutralised (sodium carbonate), concentrated to 100 ml., and extracted with ether. The combined ethereal solutions were evaporated, giving crude 2 : 4-3 : 5-*di*-O-*methylenedulcitol* (8·35 g., 81%), m. p. 99—103°, which, on crystallisation from absolute ethanol, afforded plates, m. p. 104—104·5° not depressed on admixture with a sample prepared by hydrolysis of 1 : 6-di-*O*-benzoyl-2 : 4-3 : 5-di-*O*-methylenedulcitol (Found: C, 46·6; H, 6·5. $C_8H_{14}O_6$ requires C, 46·6; H, 6·8%).

1 : 6-*Dichloro*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol.*—2 : 4-3 : 5-Di-*O*-methylenedulcitol (0·5 g.) was suspended in pyridine (2 ml.), and thionyl chloride (1·3 ml.) added. The

mixture was heated on the steam-bath for 2 hr., poured on ice, and chloroform (50 ml.) added. The brown precipitate was filtered off and washed with chloroform (50 ml.). The aqueous layer in the filtrate was separated and twice extracted with chloroform (50 ml.). The combined extracts were washed successively with saturated sodium hydrogen carbonate solution and water and dried ($MgSO_4$). Evaporation to dryness gave a yellow-brown gum, which, on being dissolved in absolute ethanol, treated with charcoal, and concentrated to 5 ml., gave 1 : 6-*dichloro*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol* (0·16 g., 27%) as needles, m. p. 75—77°. After recrystallisation from absolute ethanol the pure compound was obtained, having m. p. 77—78°, undepressed on admixture with the compound from Bouchardat's dichlorodideoxydulcitol (Found : C, 39·4; H, 4·7. $C_8H_{12}O_4Cl_2$ requires C, 39·5; H, 4·9%).

1 : 6-*Diamino*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol*.—Dichlorodimethylenedulcitol (110 g.) and 30% ammonia solution (1980 ml.) were heated in an autoclave with stirring for 24 hr. at 110—115°. Subsequent operations were carried out in an atmosphere of nitrogen. The resulting brown solution was evaporated to dryness, hydrated barium hydroxide (143 g.) and water (1100 ml.) were added, and the mixture was heated under reflux for 1 hr. It was then evaporated to dryness and the amine extracted by boiling six times with chloroform (6 × 1400 ml.). The combined extracts were dried ($MgSO_4$), and the solvent was removed. The residual brown oil was purified by several distillations under reduced pressure. The pure 1 : 6-*diamine* (56·25 g., 61%) was obtained as a colourless oil, b. p. 120—124°/0·07 mm., which solidified (Found : C, 46·7; H, 7·8; N, 13·5; Amine equivs./10^6 g., 9790. $C_8H_{16}O_4N_2$ requires C, 47·1; H, 7·8; N, 13·7%; Amine equivs./10^6 g., 9803).

The *dihydrochloride* formed needles (from aqueous ethanol), m. p. *ca.* 270° (decomp.) (Found : C, 34·7; H, 6·7; N, 10·3. $C_8H_{16}O_4N_2,2HCl$ requires C, 34·7; H, 6·5; N, 10·1%), and the *dipicrate*, yellow needles (from aqueous ethanol), m. p. 271—273° (decomp.) (Found : C, 36·1; H, 3·4; N, 16·8. $C_8H_{16}O_4N_2,2C_6H_3O_7N_3$ requires C, 36·2; H, 3·3; N, 16·9%).

1 : 6-*Dideoxy*-2 : 4-3 : 5-*di*-O-*methylene*-1 : 6-*diphthalimidodulcitol*.—Dichlorodimethylenedulcitol (10 g.), potassium phthalimide (20 g.), and *NN*-dimethylformamide (50 ml.) were heated for 6 hr. at 180°. The cold mixture was poured into water, giving a solid (17·75 g.). This was extracted (Soxhlet) with chloroform, leaving the 1 : 6-*diphthalimido-derivative* (16·2 g., 85%) which crystallised from chloroform–light petroleum (b.p. 60—80°) as needles, m. p. 277—279° (decomp.) (Found : C, 61·4; H, 4·5; N, 6·0. $C_{24}H_{20}O_8N_2$ requires C, 62·1; H, 4·3; N, 6·0%).

Hydrolysis.—(*a*) The 1 : 6-diphthalimido-compound (4·64 g.) was heated for 2 hr. at 100° with absolute ethanol (20 ml.) and 50% hydrazine hydrate (2·5 ml.). The solvent was removed by distillation, the residual mixture made acid to Congo-red with 2N-hydrochloric acid, and the precipitate of phthalhydrazide filtered off. The filtrate was evaporated to dryness, heated under reflux with barium hydroxide solution, again evaporated to dryness, and extracted with hot chloroform. The crude diamine so obtained was converted into the dihydrochloride, which crystallised from ethanol–water as needles (0·35 g., 13%), m. p. *ca.* 270° (decomp) (Found : C, 34·4; H, 6·0%).

(*b*) In a similar experiment, with the diphthalimido-compound (16·2 g.), hydrazine hydrate (8 ml.), and absolute ethanol (50 ml.), the pure diamine was isolated by distillation as a pale-yellow oil (1·8 g., 26%), b. p. 140—148° (air-bath)/0·5—1 mm.

Condensation of 1 : 6-*Diamino*-1 : 6-*dideoxy*-2 : 4-3 : 5-*di*-O-*methylenedulcitol with Phthalic Anhydride*.—The diamine (1·04 g.) was heated with phthalic anhydride (1·46 g.) at 160° for 2 hr. Some frothing occurred at first and a solid cake was soon produced. The product was then extracted (Soxhlet) with chloroform. The extract was diluted with more chloroform, boiled with charcoal, and filtered, and light petroleum (b. p. 60—80°) was added. The 1 : 6-diphthalimido-compound (0·55 g., 23%) separated from the cold solution as needles (Found : N, 6·0%), m. p. 280—281°, not depressed on admixture with the previous product.

2 : 4-3 : 5-*Di*-O-*methylenemuconitrile*.—2 : 4-3 : 5-Di-*O*-methylenemucamide (10 g.) and freshly distilled thionyl chloride (20 ml.) were heated at 100° for 6 hr. Excess of thionyl chloride was removed *in vacuo*, and finally by drying over potassium hydroxide in a desiccator. Two crystallisations of the product from absolute alcohol gave the *dinitrile* (1·6 g., 19%) as needles, m. p. 126—128° (Found : C, 49·2; H, 4·2. $C_8H_8O_4N_2$ requires C, 49·0; H, 4·1%).

1 : 6-*Di*-O-*benzoyldulcitol*.—To a suspension of dulcitol (9·1 g.) in quinoline (12·95 ml.) at 100°, benzoyl chloride (11·55 ml.) was added, and the mixture was shaken vigorously and then heated for 6 hr. Excess of benzoyl chloride was removed by addition of absolute ethanol (60 ml.) and heating for 30 min. at 100°. The solid was filtered off, washed with ethanol and ether, and crystallised from glacial acetic acid, giving colourless 1 : 6-di-*O*-benzoyldulcitol (2·05 g., 11%), m. p. and mixed m. p. 209—210°.

Attempted Preparation of 1 : 6-*Di-O-benzoyl-*2 : 4-3 : 5-*di-O-methylenedulcitol from* 1 : 3-4 : 6-*Di-O-methylenedulcitol.*—The 1 : 3-4 : 6-compound (5·15 g.), suspended in quinoline (6·5 ml.), was heated on the steam-bath and benzoyl chloride (5·8 ml.) added. The mixture was heated for 6 hr., ethanol (45 ml.) added, and heating continued for a further 30 min. The colourless crystals (7·45 g., 72%), when washed with ethanol, had m. p. 220—224° [lit., 228—231° for the 2 : 5-di-*O*-benzoyl derivative; 1 : 6-derivative (see above), m. p. 109·5—110·5°].

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129. *Metal Derivatives of* NN′-*Diarylamidines.*

By William Bradley and Ian Wright.

The ability of *NN′*-diarylamidines to form compounds with metals has been investigated. Four kinds of metal derivatives have been recognized. Their structures are discussed.

In a previous communication [1] the preparation of *NN′*-di-2-anthraquinonylformamidine and two of its metal derivatives was described, and reference was made to the stability of the cuprous compound towards chemical reagents. The present investigation is a more detailed study of the metal derivatives of *NN′*-diarylamidines and some related compounds, in particular the cuprous and silver derivatives.

Of the methods of preparing *NN′*-diarylformamidines [2] two—the reaction of ethyl orthoformate or ethyl*iso*formanilide with primary amines—have been used most frequently in the present work. The ethyl orthoformate method gave satisfactory results with all symmetrical *NN′*-diarylformamidines except those derived from the weakest bases such as 2 : 4-dinitroaniline and 2-amino-1- and 2-amino-3-nitroanthraquinone.[3] Ten new symmetrical *NN′*-diaryl derivatives of formamidine were thus prepared. Two others, the 2 : 4-dimethylphenyl and 2-anthryl derivatives, were prepared for the first time by the ethyl orthoformate method; the second had been prepared and analysed by Bollert [4] who, however, did not record the melting point. Ethyl*iso*formanilide and benzidine gave the 4 : 4′-di-(*N*-phenylformamidine) derivative of diphenyl. Several unsymmetrical *NN′*-diarylformamidines were prepared from primary amines and ethyl*iso*formanilide.

A number of related benzamidines have been prepared, the majority by the reaction of benzotrichloride with amines, and also a series of acetamidines from imidoyl chlorides by reaction with amines.[2] In addition some metal derivatives of compounds related to the amidines have been investigated; these included the dianil and the di-(*p*-chloroanil) of glutacondialdehyde, 2-*p*-nitroanilinoquinoline, 2 : 4 : 6-triarylaminotriazines, the dianils of dimedone and indane-1 : 3-dione, benziminazole, and di-(2-methyl-3-indenyl)methine.

NN′-*Diarylformamidines.*—Most of the formamidines were colourless or pale yellow crystalline solids. A few were more deeply coloured, such as the symmetrical compounds derived from *p*-aminoazobenzene (orange), 2-aminofluorenone (red), and 3-aminofluorenone (reddish-orange). *N*-2-Anthraquinonyl-*N′*-phenylformamidine was orange-yellow.

Cuprous derivatives. Most of these were obtained from the parent formamidines by one or both of two methods.

(1) Reaction with cupric acetate in ethanol. This succeeded with compounds which were readily oxidised, *e.g.*, the di-*p*-alkylphenyl and di-*p*-alkoxyphenyl members, but the more stable ones, *e.g.*, *NN′*-di-*p*-nitrophenylformamidine, which did not reduce cupric acetate, did not yield cuprous derivatives by this method. The maximum molar yield obtainable did not exceed one-half of the amount of formamidine employed. In several

[1] Bradley and Leete, *J.*, 1951, 2147.
[2] Shriner and Neumann, *Chem. Rev.*, 1944, **35**, 351.
[3] Cf. Mizumo and Nishimura, *J. Pharm. Soc. Japan*, 1948, **68**, 58.
[4] Bollert, *Ber.*, 1883, **16**, 1639.

instances, as with the *NN'*-di-*p*-acetylphenyl and *NN'*-di-*p*-methylsulphonyl members, there was evidence that the formamidines were decomposed by the solvent.[5] *NN'*-Di-*p*-chlorophenylformamidine formed a stable addition compound with cupric acetate.

With the less soluble symmetrical formamidines, *e.g.*, those derived from 2-aminoanthraquinone and 2-aminoanthracene, nitrobenzene was preferred to alcohol, but even in this medium scission of the formamidine to the component amines was observed with the *NN'*-di-*p*-nitrophenyl and *NN'*-di-2-fluorenonyl compounds. Yields obtained by reaction in boiling nitrobenzene sometimes exceeded those obtained in alcohol; it may be mentioned in this connection that cupric acetate yields cuprous acetate at high temperatures.[6]

(2) A more general method was to mix pyridine solutions of the formamidines and cuprous chloride, the latter in twice the theoretical amount, to add then sufficient of a standard solution of potassium hydroxide or methoxide in methanol, and finally to add the whole to water. After purification 80—90% yields of the cuprous derivatives were obtained.

The cuprous derivatives were solids, mostly crystalline, which gave analyses correct for the expected compound. Solubility varied with structure, the di-*p*-*n*-butoxyphenyl member being soluble in cold benzene, whilst cuprous *NN'*-di-2-anthraquinonylformamidine was insoluble in hot nitrobenzene; the majority were soluble to some degree in benzene or chlorobenzene. In a series of *pp'*-disubstituted derivatives of *NN'*-diphenylformamidine the solubility in organic solvents diminished in the order $Bu^nO > Bu^tO > EtO > MeO > Me > H > Cl > Ac > NO_2$. All the cuprous derivatives melted and then decomposed, the majority in the range 220—360°. That of *NN'*-di-*p*-*n*-butoxyphenylformamidine melted without decomposition at 163°. Colour was generally similar to that of the parent formamidine except with *NN'*-di-2-anthraquinonyl (red-violet), *NN'*-di-2-fluorenonyl (blue-violet), and *NN'*-di-3-fluorenonyl (red-violet); *N*-2-anthraquinonyl-*N'*-phenylformamidine afforded a violet cuprous derivative. Stability towards chemical reagents varied with structure; none was so inert as cuprous *NN'*-di-2-anthraquinonylformamidine.[1] All were stable towards cold, N-potassium hydroxide, but all reacted slowly with cold aqueous sodium sulphide, potassium cyanide, and N-hydrochloric acid except the *NN'*-di-2-anthraquinonyl compound. The cuprous derivatives showed no tendency to oxidation by air, even when moist. Their behaviour in hot pyridine varied considerably. Cuprous *NN'*-diphenylformamidine could be crystallised from this medium, though decomposition occurred when the heating was more than brief, but the cuprous compounds of *NN'*-di-*p*-nitrophenyl- and *NN'*-di-*p*-acetylphenyl-formamidine were transformed into cupric derivatives which then crystallised with 4 mols. of the solvent.

Silver derivatives. These were usually prepared by the addition of a solution of silver acetate in pyridine to one of the formamidine in pyridine or methanol. All were obtained crystalline. Their solubilities in organic solvents were generally higher than those of the cuprous derivatives; the silver compounds of the 4 : 4'-dimethoxy-, 4 : 4'-diethoxy-, and 4 : 4'-di-*n*-butoxy-derivatives of *NN'*-diphenylformamidine were soluble in benzene and the di-*n*-butoxy-compound was soluble also in light petroleum (b. p. 60—80°). All decomposed on being heated. Their colours varied with structure in the same way as the cuprous compounds, and in the several examples investigated the absorption spectra of the silver and the cuprous compounds were closely similar. None was markedly sensitive to light.

NN'*-Diarylacetamidines and* NN'*-Diarylbenzamidines.*—Most of the methods of preparing the cuprous derivatives of *NN'*-diarylformamidines failed with the corresponding acetamidines and benzamidines. The cuprous derivatives of *NN'*-di-2-anthraquinonyl- and *NN'*-di-*p*-nitrophenyl-benzamidine resulted when the parent compounds were heated with copper bronze in nitrobenzene but the method was not generally useful. The cuprous derivatives which were isolated resembled the corresponding formamidine compounds closely, except that cuprous *NN'*-di-2-anthraquinonylformamidine was much more stable than the related benzamidine.[1] Silver derivatives could not be prepared.

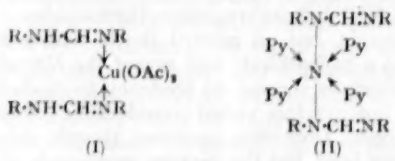
Related Compounds.—2-*p*-Nitroanilinoquinoline afforded a yellow cuprous derivative with copper in nitrobenzene. Benziminazole gave a grey product by method (2), but this

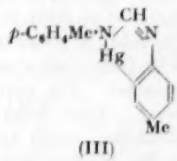
[5] Cf. Dains, *Ber.*, 1902, **35**, 2498.
[6] Sidgwick, "Chemical Elements and their Compounds," Clarendon Press, Oxford, 1950, p. 126.

changed to the known red cupric compound [7] on contact with ammonia and ammonium chloride. Glutacondialdehyde dianil afforded a violet cuprous derivative by method (2), and an analogous compound was prepared from the di-*p*-chloro-anil; unlike the parent dianils both cuprous derivatives were stable and also unaffected by ammonia–ammonium chloride. Acetylacetone dianil gave a cupric derivative when it was brought into contact with an ammoniacal cupric solution. Indane-1 : 3-dione dianil and cupric acetate in ethanol or cuprous chloride in pyridine gave a deep red cuprous derivative which was unstable towards aqueous ammonia.

Cupric Derivatives of NN′*-Diarylformamidines.*—*NN′*-Diphenyl- and *NN′*-di-*p*-tolyl-formamidine combined with cupric acetate to form green, unstable complexes having the composition (I). Attempts to replace two atoms of hydrogen by one atom of copper in two mols. of *NN′*-di-2-anthraquinonylformamidine were unsuccessful, but tetrapyridine adducts of analogous copper and nickel compounds of *NN′*-di-*p*-nitrophenylformamidine were prepared; the copper compound readily lost two mols. of pyridine on being heated.

Structure of the Metal Derivatives of NN′*-Diarylamidines.*—*NN′*-Diarylamidines form potassium derivatives which have the properties of salts of weak acids; as such they are easily hydrolysed by water with liberation of the parent amidine. In addition *NN′*-diphenyl- and *NN′*-di-*p*-tolyl-formamidine are able to function as simple donors. They yield adducts with cupric acetate which contain two mols. of the amidine to one of the cupric salt and are soluble in benzene and decomposed by water; the adducts behave as fully covalent compounds. Thus the *NN′*-diphenylformamidine–cupric acetate compound has a molecular weight of 506 in benzene (cryoscopic) [$C_{26}H_{24}N_4Cu(C_4H_6O_4)$ requires 574]. The cupric and nickel derivatives, in which one atom of metal replaces two atoms of hydrogen in two mols. of an amidine and the product combines with pyridine, are presumably co-ordination compounds also, the nickel derivative being represented by (II).





Mercuric acetate reacts with *NN′*-di-*p*-tolylformamidine to form a derivative, $C_{15}H_{14}N_2Hg$, which with iodine affords *N*-(2-iodo-4-methylphenyl)-*N′*-phenylformamidine. The most probable structure of the mercury compound appears to be (III).

Especially interesting are the cuprous and silver derivatives which are formed by all the formamidines investigated. They have the character of inner complexes.[1] Unlike the cupric compounds referred to they are stable to water, aqueous ammonia, and generally also aqueous ammonia containing ammonium chloride. In cuprous *NN′*-di-2-anthraquinonylformamidine the metal has replaced hydrogen which was attached to nitrogen in the parent compound, because the same cuprous derivative results whether *NN′*-di-2-anthraquinonylformamidine or its *N*-methyl derivative is used in the preparation; when the *N*-methyl derivative is used the methyl group is eliminated.[1] The close correspondence in properties suggests that the same kind of Cu–N bond is present in all the cuprous derivatives and an analogous Ag–N bond in the related silver compounds. The decomposition of cuprous *NN′*-diphenylformamidine with hydrochloric acid under nitrogen liberates copper in the form of cuprous ions only. As to the size of the molecules, determinations of the molecular weights of cuprous and silver compounds in benzene by the ebullioscopic method gave the results shown in the following Table. The three compounds investigated are thus tetrameric in boiling benzene but this is not necessarily so for all cuprous and silver compounds under all circumstances. The parent *NN′*-diarylformamidines are associated [8] and cyclic dimeric and linear polymer forms have been proposed.[8, 9] Similar considerations

[7] Cf. Skraup, *Annalen*, 1919, **419**, 70.
[8] Roberts, *J. Amer. Chem. Soc.*, 1950, **72**, 3608.
[9] Hunter and Marriott, *J.*, 1941, 777.

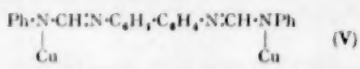
apply to the *NN'*-diarylacetamidines and *NN'*-diarylbenzamidines.[9] In associating, the *NN'*-diarylformamidines resemble the analogously constituted 1 : 3-diaryltriazens.[10] The metal derivatives of the latter have been examined by Dwyer [11] who concludes that the cuprous and silver derivatives of 1 : 3-diphenyltriazen are monomeric in benzene and

Derivative	Mol. wt. found	4 × Formula weight
Cuprous *NN'*-di-*p*-*n*-butoxyphenylformamidine	1650	1610
Silver *NN'*-di-*p*-methoxyphenylformamidine	1450	1451
Silver *NN'*-di-*p*-*n*-butoxyphenylformamidine	1875	1788

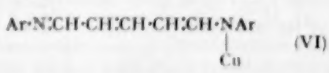
contain a 4-membered ring. Under the conditions we have employed we found cuprous 1 : 3-diphenyltriazen to be considerably associated (Found : *M*, 1136, 998, 804. Calc. for $C_{12}H_{10}N_3Cu$: *M*, 260·6). A decision as to the structure of the tetrameric cuprous and silver derivatives of the *NN'*-diarylformamidines is not possible in the absence of *X*-ray crystallographic measurements but a cyclic form involving four molecules of the metal derivative in which each atom of copper or silver is linked to nitrogen, the nitrogen–metal bonds being linear, appears most probable (cf. IV). Other metal derivatives may be linear polymers which contain the same repeating unit as (IV); indeed a linear polymer form appears to be the more probable for such compounds as the dicuprous derivatives (V) and the cuprous derivatives of glutacondialdehyde dianil and the di-*p*-chloro-anil (VI; Ar = Ph or *p*-C_6H_4Cl).

Inner complexes have been prepared previously from a number of cyclic vinylogues of the formamidines. *o*-Aminobenzaldimine forms a green, and pyrrole-2-aldimine a red, cupric derivative.[12] Similar properties are shown by 2-2′-pyridylpyrrole,[13] 2-alkylimino-

(IV)



(V)



(VI)

methylpyrroles,[14] the 2 : 2′-dipyrrylazomethines,[15] the 2 : 2′-dipyrrylmethines,[16] and the phthalocyanines.[17] Indeed, cuprous complexes appear to be restricted to those derived from 1 : 3-diphenyltriazen,[11] di-(2-methyl-3-indenyl)methine,[18] di-(3 : 5-dimethyl-2-pyrryl)*meso*phenylmethine,[15] and those now reported. With the formamidines the ready polarizability of the anion doubtless contributes to the stability of the cuprous form.[19]

Experimental

NN'-Diarylformamidines.—Several *NN'*-diarylformamidines were prepared by methods described in the literature. New symmetrical compounds were prepared by heating ethyl orthoformate with primary amines; all unsymmetrical compounds were obtained by the action of ethyl*iso*formanilide on primary amines (Table 1). Additional details are given in Table 2. 2-Aminoanthraquinone (2·2 g.) and ethyl*iso*formanilide (2·0 g.) gave *N*-2-anthraquinonyl-*N'*-phenylformamidine (1·0 g.; orange-yellow needles from chlorobenzene, readily soluble in pyridine) and *NN'*-di-2-anthraquinonylformamidine (0·9 g.).

NN'-Di-(N-phenylformimidoyl)benzidine.—Benzidine (4·5 g.) and ethyl*iso*formanilide (8 g.) were heated to 180° during 0·5 hr. and kept thereat for 0·5 hr. The solid product was cooled and extracted with benzene; the *diformamidine* separated and was crystallised from benzene

[9] Hunter, *J.*, 1937, 320.
[10] Dwyer, *J. Amer. Chem. Soc.*, 1941, **63**, 78, *J. Soc. Chem. Ind.*, 1939, **58**, 110.
[11] Pfeiffer, *J. prakt. Chem.*, 1937, **149**, 217.
[12] Emmert and Brandl, *Ber.*, 1927, **60**, 2211.
[13] Emmert, Diehl, and Gollwitzer, *Ber.*, 1929, **62**, 1733.
[14] Rogers, *J.*, 1943, 596.
[15] Fischer and Schubert, *Ber.*, 1923, **56**, 1202; 1924, **57**, 611; Fischer and Ammann, *Ber.*, 1923, **56**, 2319; Porter, *J.*, 1938, 368; Rogers, *J.*, 1943, 596.
[16] Barrett, Dent, and Linstead, *J.*, 1936, 1719.
[17] Kunz and Stühlinger, *Ber.*, 1925, **58**, 1866; Schmitz-Dumont and Motzkus, *Ber.*, 1928, **61**, 580.
[18] Randles, *J.*, 1941, 802.

TABLE 1. *NN'-Diarylformamidines.*

NN'-Subst.	$H{\cdot}C(OEt)_3$ (g.)	Amine (g.)	Yield (g.)	Colour [a]	Solvent
p-$C_6H_4Bu^t$	5	7·5	3·0	Colourless	Pet [b]
p-$C_6H_4{\cdot}OBu^n$	5	8·25	7·0	,,	,,
o-$C_6H_4{\cdot}NO_2$	7	10·3	1·0	Yellow	EtOH
p-C_6H_4Ac	7·5	6·8	5·9	Yellow	C_6H_6
p-$C_6H_4{\cdot}SO_2{\cdot}Me$	5	8	7·5	White (amorphous)	
p-$C_6H_4{\cdot}CO_2Et$	5	8	7·5	Colourless	C_6H_6
2-Fluorenyl	2	3·6	1·9	Yellow	PhCl
2-Fluorenonyl	3	4	2	Red	$PhNO_2$
5-Quinolyl	0·8	1·4	0·7	Colourless	C_6H_6

[a] Needles, except as stated. [b] Light petroleum of b. p. 60—80°.

TABLE 2. *NN'-Diarylformamidines.*

		Found (%)				Required (%)		
NN'-Subst.[a]	M. p.	C	H	N	Formula	C	H	N
p-$C_6H_4Bu^t$	163°	81·5	9·3	9·2	$C_{21}H_{28}N_2$	81·8	9·1	9·1
p-$C_6H_4{\cdot}OBu^n$	98—99	74·2	7·9	8·4	$C_{21}H_{28}O_2N_2$	74·1	8·2	8·2
o-$C_6H_4{\cdot}NO_2$	161	54·1	3·3	19·7	$C_{13}H_{10}O_4N_4$	54·5	3·5	19·6
p-C_6H_4Ac	172	72·7	5·7	10·1	$C_{17}H_{16}O_2N_2$	72·9	5·7	10·1
p-$C_6H_4{\cdot}SO_2{\cdot}Me$	218—221	51·3	4·9	8·2	$C_{15}H_{16}O_4N_2S_2$	51·1	4·6	8·0
p-$C_6H_4{\cdot}CO_2Et$	191	67·5	6·0	8·2	$C_{19}H_{20}O_4N_2$	67·1	5·9	8·2
2-Fluorenyl	253—254	87·4	4·9	7·6	$C_{27}H_{20}N_2$	87·1	5·4	7·5
2-Fluorenonyl	264—265	81·3	3·8	6·8	$C_{27}H_{16}O_2N_2$	81·0	4·0	7·0
5-Quinolyl	203	—	—	18·5, 18·9	$C_{19}H_{14}N_4$	—	—	18·8

[a] *N-2-Anthraquinonyl-N'-phenylformamidine* has m. p. 235—236° (Found: C, 77·3; H, 4·1; N, 8·9. $C_{21}H_{14}O_2N_2$ requires C, 77·3; H, 4·3; N, 8·6%).

(m. p. 225—226°) and then from chlorobenzene (5 g.; m. p. 225°) (Found: C, 79·8; H, 5·9; N, 14·1. $C_{26}H_{22}N_4$ requires C, 80·0; H, 5·6; N, 14·4%).

N-(2-Iodo-4-methylphenyl)-N'-p-tolylformamidine.—2-Iodo-4-methylaniline (4·6 g.) and ethyl-4-*iso*formamidotoluene (3·5 g.) were heated for 2 hr. at 180°. The cooled product was a thick oil which crystallised on being stirred with light petroleum (15 c.c.; b. p. 60—80°). The solid product was collected, washed with light petroleum (yield, 3·4 g.), and crystallised from benzene; it had m. p. 154—155° (Found: C, 52·1; H, 4·1; N, 7·7; I, 35·8. $C_{15}H_{15}N_2I$ requires C, 51·4; H, 4·3; N, 8·0; I, 36·3%).

Cuprous NN'-Diphenylformamidine.—(*a*) Cupric acetate (1 g.) and *NN'*-diphenylformamidine (1 g.; m. p. 139°, cf. Claisen [20]) were refluxed for 1 hr. in ethanol (40 c.c.). Needles (0·3 g.) separated and were collected and washed with hot ethanol. *Cuprous NN'-diphenylformamidine* crystallised from benzene and chlorobenzene in pale yellow needles, m. p. 310° (decomp.) (Found: C, 60·2; H, 4·3; N, 10·8; Cu, 24·5. $C_{13}H_{11}N_2Cu$ requires C, 60·3; H, 4·3; N, 10·8; Cu, 24·6%). It was insoluble in alcohol and water. (*b*) The same product (0·5 g.) resulted in the following experiment. Cupric acetate (0·5 g.) was dissolved in dilute aqueous ammonia. Air was displaced from the solution by means of nitrogen and an excess of hydrazine sulphate was added. The resulting colourless solution was mixed under nitrogen with one of *NN'*-diphenylformamidine (0·5 g.) in ethanol. The voluminous precipitate was collected and then kept in contact with aqueous ammonia–ammonium chloride for 48 hr. The residue was collected, washed with water, then with ethanol, and crystallised from chlorobenzene.

Silver NN'-diphenylformamidine resulted when a filtered solution of silver acetate (0·9 g.) in pyridine (10 c.c.) was added slowly to one of *NN'*-diphenylformamidine (1 g.) in methanol (15 c.c.). The precipitate was collected, washed with a small volume of pyridine and methanol, and then kept in contact with cold dilute ammonia for 24 hr. Silver *NN'*-diphenylformamidine crystallised from a small volume of pyridine as needles, m. p. 260° (decomp.) (Found: C, 51·8; H, 3·8; N, 9·2; Ag, 35·8. $C_{13}H_{11}N_2Ag$ requires C, 51·5; H, 3·6; N, 9·2; Ag, 35·7%). The same derivative was formed on addition of an alcoholic solution of *NN'*-diphenylformamidine to one of silver acetate in dilute ammonia.

Cuprous NN'-di-p-methoxyphenylformamidine.—Equimolar amounts of cuprous chloride and *NN'*-di-*p*-methoxyphenylformamidine were refluxed for 1 hr. in dry ethanol. The suspension, filtered while hot, gave a grey residue and this was stirred with dilute aqueous ammonia. The

[20] Claisen, *Annalen*, 1895, **287**, 366.

insoluble derivative crystallised from benzene as greenish-yellow needles, m. p. 269—270°, without prior decomposition, and as pale yellow needles, m. p. 269—270°, from dioxan or dioxan–ethanol (Found : C, 56·5; H, 5·0; N, 9·2; Cu, 19·8. $C_{15}H_{15}O_2N_2Cu$ requires C, 56·5; H, 4·7; N, 8·8; Cu, 20·0%).

Cuprous NN'-Di-o-chlorophenylformamidine.—Cuprous chloride (1 g.) was dissolved in hot pyridine under nitrogen, and the resulting solution was passed into a warm solution of *NN'*-di-*o*-chlorophenylformamidine (1·3 g.) in pyridine. Methanolic potassium hydroxide (2·5 c.c. of 2N) was added, and the mixture was shaken and poured into water. Concentrated aqueous ammonia was added to the resulting suspension and after some hours the solid was collected, washed with aqueous ammonia, then with ethanol, and finally boiled with ethanol (150 c.c.). The white insoluble residue of *cuprous NN'-di-o-chlorophenylformamidine* crystallised from chlorobenzene as colourless needles (0·7 g.), m. p. 287° (decomp.) (Found : C, 47·7; H, 3·0; N, 8·4; Cl, 22·0; Cu, 19·1. $C_{13}H_9N_2Cl_2Cu$ requires C, 47·6; H, 2·8; N, 8·6; Cl, 21·7; Cu, 19·4%). This product was identical with the cuprous derivative prepared from *NN'*-di-*o*-chlorophenylformamidine (1 g.) and cupric acetate (1 g.) in ethanol (40 c.c.) (Found : C, 47·7; H, 2·9%).

Details of other cuprous and silver compounds are given in Tables 3 and 4. *NN'*-Di-(*N*-phenylformimidoyl)benzidine (0·9 g., 0·0025 mol.) and cuprous chloride (2·0 g.) in pyridine under nitrogen gave a greenish-yellow *dicuprous derivative* (Found : Cu, 22·5. $C_{26}H_{20}N_4Cu_2$ requires

TABLE 3. *Cuprous derivatives of NN'-diarylformamidines.*

			Found (%)					Required (%)			
NN'-Subst.	Method of prep.	M. p. (decomp.)	C	H	N	Cu	Formula	C	H	N	Cu
p-C_6H_4Me	(*a*)	330—332°	63·0	5·4	9·9	21·8	$C_{15}H_{15}N_2Cu$	62·8	5·2	9·8	22·2
p-$C_6H_4Bu^t$	(*a*)	397 *	67·7	7·3	7·2	17·2	$C_{21}H_{27}N_2Cu$	68·0	7·3	7·6	17·2
p-C_6H_4·OEt ...	(*a*)	220	—	—	7·8	18·0	$C_{17}H_{19}O_2N_2Cu$	—	—	8·1	18·4
p-C_6H_4·OBu^n ...	(*a*)	163	63·0	6·9	7·4	15·4	$C_{21}H_{27}O_2N_2Cu$	62·6	6·7	7·0	15·8
p-C_6H_4Cl	(*c*)	318—320	47·4	3·1	8·3	—	$C_{13}H_9N_2Cl_2Cu$	47·6	2·8	8·6	—
p-C_6H_4·NO_2 ...	(*c*)	>400	44·8	2·8	15·8	17·8	$C_{13}H_9O_4N_4Cu$	44·7	2·6	16·1	18·2
p-C_6H_4Ac	(*c*)	†	59·1	4·7	18·3	18·1	$C_{17}H_{15}O_2N_2Cu$	59·5	4·4	8·2	18·6
p-C_6H_4·CO_2Et	(*c*)	320	56·5	4·7	6·8	15·7	$C_{19}H_{19}O_4N_2Cu$	56·6	4·7	7·0	15·8
p-C_6H_4·N_2Ph ...	(*c*)	336—338	64·2	4·2	17·9	—	$C_{25}H_{19}N_4Cu$	64·3	4·1	18·0	—
2-Anthryl	(*d*)	—	75·4	3·9	6·0	13·9	$C_{29}H_{19}N_2Cu$	75·9	4·1	6·1	13·9
2-Fluorenonyl	(*c*)	—	—	—	6·0	13·8	$C_{27}H_{15}O_2N_2Cu$	—	—	6·1	13·7
5-Quinolyl	(*c*)	235 ‡	—	—	—	17·9	$C_{19}H_{13}N_4Cu$	—	—	—	17·6

* Decomp. from 350°. † Decomp. without melting above 220°. ‡ Darkens at 230°.
Methods of prep. : (*a*) cupric acetate in alcohol; (*b*) cuprous chloride in alcohol; (*c*) cuprous chloride in pyridine; (*d*) cupric acetate in nitrobenzene.

TABLE 4. *Silver derivatives of NN'-diarylformamidines.*

		Found (%)					Required (%)			
NN'-Subst.	M. p. (decomp.)	C	H	N	Ag	Formula	C	H	N	Ag
p-C_6H_4·OMe	205°	49·7	4·3	7·9	29·8	$C_{15}H_{15}O_2N_2Ag$	49·5	4·1	7·7	29·7
p-C_6H_4·OEt	215	52·4	4·9	7·1	27·6	$C_{17}H_{19}O_2N_2Ag$	52·2	4·9	7·2	27·6
p-C_6H_4·OBu^n	185	56·6	6·6	6·1	24·4	$C_{21}H_{27}O_2N_2Ag$	56·4	6·0	6·3	24·2
p-C_6H_4·NO_2	318	39·5	2·2	14·2	27·1	$C_{13}H_9O_4N_4Ag$	39·7	2·3	14·3	27·5
p-C_6H_4Ac	—	52·9	3·8	7·3	27·3	$C_{17}H_{15}O_2N_2Ag$	52·7	3·9	7·2	27·9

Cu, 24·7%) on addition to a fine suspension of potassium methoxide (0·005 mol.) in pyridine. *Cuprous N-p-nitrophenyl-N'-phenylformamidine*, yellow needles (from *o*-dichlorobenzene), m. p. >300° (Found : C, 51·5; H, 3·4; N, 13·9, Cu, 20·7. $C_{13}H_{10}O_2N_3Cu$ requires C, 51·4; H, 3·3; N, 13·8; Cu, 21·0%) and *N-2-anthraquinonyl-N'-phenylformamidine*, a violet powder (Found : N, 7·4; Cu, 17·1. $C_{21}H_{13}O_2N_2Cu$ requires N, 7·2; Cu, 16·4%), were prepared by method (*c*) (see Table 3). *Silver N-p-nitrophenyl-N'-phenylformamidine*, yellow needles (from pyridine), has m. p. 264—265° (Found : C, 45·1; H, 3·0; N, 12·4; Ag, 31·0. $C_{13}H_{10}O_2N_3Ag$ requires C, 44·8; H, 2·9; N, 12·1; Ag, 31·0%).

Oxidation State of Copper in Cuprous NN'-Diphenylformamidine.—The copper derivative of *NN'*-diphenylformamidine (0·07 g.) was dissolved in concentrated hydrochloric acid (5 c.c.) under nitrogen. The solution so obtained was passed into 20 c.c. of an aqueous solution of sodium acetate (10 g.); a fine white suspension of the metal-free formamidine resulted. On the addition of potassium iodide (1 g.) in water (5 c.c.) there was no liberation of iodine, and on the further

addition of aqueous ammonia only a very faint blue colour developed; contact with air caused rapid oxidation of the cuprous ion to the cupric state.

Silver NN'-Di-2-anthraquinonylformamidine.—An equivalent of potassium dissolved in methanol was added to a suspension of *NN'*-di-2-anthraquinonylformamidine (0·4 g.) in dry pyridine (100 c.c.). A deep blue colour developed; conversion into the potassium salt was completed by heating the suspension for 15 min. under reflux. A solution of silver acetate (0·2 g.) in pyridine (25 c.c.) was then added and refluxing was continued for 5 min.; the colour changed to violet-brown. The cooled suspension was then filtered, and the residue washed with water, then with cold aqueous ammonia. On being dried the *product* became paler and browner (Found: Ag, 18·5. $C_{29}H_{16}O_4N_2Ag$ requires Ag, 19·2%). Exposure of the dry solid to ammonia fumes restored the dark violet-brown colour.

NN'-Di-p-nitrophenylacetamidine.—*p*-Nitroacetanilide (1·8 g.) was added to a solution of phosphorus pentachloride (2·3 g.) in nitrobenzene (30 c.c.) which had been prepared at 100° and then cooled. The mixture was heated at 120° until a clear solution resulted (2 hr.). *p*-Nitroaniline (1·4 g.) was added and the heating was continued at 140° for 3 hr. On being cooled and kept the solution afforded crystals; these were collected and decomposed by the addition of ammonia. *NN'-Di-p-nitrophenylacetamidine* crystallised from ethanol as yellow needles, m. p. 261—262° (softening at 252°) (Found: C, 56·2; H, 4·3; N, 18·9. $C_{14}H_{12}O_4N_4$ requires C, 56·0; H, 4·0; N, 18·7%).

NN'-Di-2-anthraquinonylacetamidine.—Prepared analogously from 2-acetamidoanthraquinone (13·25 g.) and phosphorus pentachloride (12 g.) in nitrobenzene (100 c.c.) with subsequent addition of 2-aminoanthraquinone (12 g.), this *product* (10 g.) crystallised from pyridine as yellow needles, m. p. 350—352° (Found: C, 76·5; H, 3·7; N, 5·9. $C_{30}H_{18}O_4N_2$ requires C, 76·6; H, 3·8; N, 6·0%).

p-Nitro-NN'-diphenylbenzamidine.—Prepared from *p*-nitrobenzanilide (6 g.) by heating with a solution of phosphorus pentachloride (6 g.) in nitrobenzene and further treatment of the product with aniline (2·4 g.), this *amidine* crystallised from ethanol as yellow plates, m. p. 157° (Found: C, 71·4; H, 4·8; N, 13·1. $C_{19}H_{15}O_2N_3$ requires C, 71·9; H, 4·7; N, 13·2%). The cuprous derivative resulted when the benzamidine (3·6 g.) and copper bronze (1 g.) were refluxed for 3·5 hr. in nitrobenzene (25—30 c.c.). On being filtered the suspension yielded a residue; this was washed with acetone and then treated for 72 hr. with a concentrated solution of ammonium chloride in ammonia (*d* 0·88). The resulting solid was collected, washed free from copper salts, and extracted with acetone. *Cuprous* p-*nitro*-NN'-*diphenylbenzamidine* forms brown needles (yellow on being crushed) (Found: C, 53·3; H, 3·4; N, 13·0; Cu, 15·0. $C_{19}H_{13}O_4N_4Cu$ requires C, 53·7; H, 3·1; N, 13·2; Cu, 15·0%).

Reaction of Cuprous Chloride with Glutacondialdehyde Dianil.—A solution of cuprous chloride (1 g.) in pyridine was added to one of glutacondialdehyde dianil [21] (1 g.) in pyridine. Methanolic potassium methoxide (1·4 c.c. of 2N) was added, all the manipulations being done under nitrogen. The mixture was shaken, then added to water; a brown precipitate was formed. Concentrated aqueous ammonia was added, and the precipitate was collected, then stirred with ammonia, again collected, then dried *in vacuo*. The resulting solid was extracted with acetone; a purple residue remained which decomposed at 175° (Found: C, 61·1, 64·5; H, 4·5, 4·0; N, 9·0; Cu, 19·9, 19·6. $C_{17}H_{12}N_2Cu$ requires C, 65·7; H, 4·8; N, 9·0; Cu, 20·5%). The combined copper was not removed on extraction with aqueous ammonia–ammonium chloride. The copper derivative was slightly soluble in benzene with a deep red-violet colour which rapidly faded to yellow.

Similar treatment of glutacondialdehyde di-(*p*-chloroanil) hydrochloride [21] (1 g.) with cuprous chloride (1 g.) and methanolic potassium methoxide (3 c.c. of 2N) gave a purplish-brown, copper-containing product which decomposed at 200—201° (Found: Cu, 15·9. Calc. for $C_{17}H_{10}N_2Cl_2Cu$: Cu, 17·1%).

Copper Derivative of Acetylacetone Dianil.—(*a*) Application of the procedure used with glutacondialdehyde dianil to acetylacetone dianil hydrochloride (1·43 g.), cuprous chloride (1 g.), and methanolic potassium methoxide (5 c.c. of 2N) gave dark green material most of which was soluble in acetone. Evaporation of the extract under reduced pressure gave black plates which afforded the *cupric derivative* as a green powder, m. p. 157—158° (on being crushed); the m. p. was unaltered after further crystallisation from acetone (Found: C, 72·5; H, 6·0; N, 9·9; Cu, 11·3. $C_{34}H_{34}N_4Cu$ requires C, 72·6; H, 6·1; N, 10·0; Cu, 11·3%). (*b*) The same cupric compound, m. p. and mixed m. p. 157—158°, resulted from the action of ammoniacal cupric acetate on acetylacetone dianil hydrochloride.

[21] Zincke, *Annalen*, 1904, **333**, 296.

2-p-*Nitroanilinoquinoline.*—2-Chloroquinoline (5 g.) and *p*-nitroaniline (5 g.) were heated at 180° for 1·5 hr. The cooled melt was crushed and then extracted with alcohol (600 c.c.). The filtered solution afforded crystals (5·5 g.) and these on further purification from alcohol gave 2-p-*nitroanilinoquinoline* as yellow-orange needles, m. p. 229° (Found : C, 68·2; H, 4·4; N, 16·0. $C_{15}H_{11}O_2N_3$ requires C, 67·9; H, 4·2; N, 15·9%). On being refluxed for 5 hr. with copper bronze (0·25 g.) and nitrobenzene (20 c.c.) 2-*p*-nitroanilinoquinoline (0·6 g.) afforded a *cuprous derivative*. This was obtained, mixed with copper bronze, when the suspension was cooled. The unchanged metal was dissolved by treatment with a solution of ammonium chloride in concentrated aqueous ammonia, and the residual yellow needles were collected, washed, and then extracted with alcohol (Found : C, 54·6; H, 3·3; N, 12·9; Cu, 19·7. $C_{15}H_{10}O_2N_3Cu$ requires C, 55·0; H, 3·1; N, 12·8; Cu, 19·4%). In hot pyridine it gave a solution which was red initially but changed to yellow on boiling.

Mercury Derivative of NN'-*Di*-p-*tolylformamidine.*—Mercuric acetate (1·6 g.) and *NN'*-di-*p*-tolylformamidine (1·1 g.) were refluxed in ethanol (40 c.c.). After 30 mins. a clear yellow solution resulted, from which on further heating a yellow solid separated. The solid was collected from the hot suspension and crystallised from pyridine. The *mercury derivative* formed pale yellow needles, m. p. 320° (Found : C, 42·9; H, 3·5; N, 6·8. $C_{15}H_{14}N_2Hg$ requires C, 42·6; H, 3·3; N, 6·6%), insoluble in water and unaffected on brief heating with aqueous ammonia or sodium sulphide.

Reaction with iodine. A suspension of the mercury derivative (2·5 g.) in ethanol (50 c.c.) was refluxed with an ethanol solution (18 c.c.) of iodine (2·28 g.); reaction was complete in 15 min. The resulting solution was cooled, a small amount of solid was filtered off, and water was added to the filtrate. A sticky reddish precipitate formed; this was stirred with potassium iodide and the resulting granular solid was collected, treated with charcoal in alcohol, and reprecipitated by addition to aqueous potassium iodide. The yellow solid was collected, dried (yield, 0·9 g.), and crystallised from benzene–light petroleum (b. p. 60—80°). It formed white crystals, m. p. 151—152° (Found : N, 8·2; I, 36·2. Calc. for $C_{15}H_{15}N_2I$: N, 8·0; I, 36·3%), which did not depress the m. p. of *N*-(2-iodo-4-methylphenyl)-*N'*-*p*-tolylformamidine. Iodine (0·127 g.) in ethanol (1 c.c.) did not react with *NN'*-di-*p*-tolylformamidine (0·45 g.) in boiling ethanol (20 c.c.) during 2 hr.

Cupric Complexes.—(*a*) A solution of cupric acetate (0·5 g.) and *NN'*-diphenylformamidine (1 g.) in methanol was evaporated under reduced pressure until crystallisation occurred. The resulting suspension was cooled in ice-salt and the deep green crystals which separated were collected, dried *in vacuo*, and recrystallised (yield, 0·7 g.) by dissolution in benzene and addition of light petroleum (b. p. 60—80°). *Bis*-(NN'-*diphenylformamidine*)*cupric acetate* shrinks at 164° (Found : C, 63·0; H, 5·3; N, 9·6; Cu, 10·8. $C_{30}H_{30}O_4N_4Cu$ requires C, 62·8; H, 5·2; N, 9·8; Cu, 11·1%); it is dissociated into *NN'*-diphenylformamidine and cupric salt by contact with water.

(*b*) Similar treatment of *NN'*-di-*p*-tolylformamidine (1 g.) gave *bis*-(NN'-*di*-p-*tolylformamidine*)-*cupric acetate* (1 g.) as green crystals which shrink at 173° (Found : C, 65·3; H, 6·0; N, 8·9; Cu, 10·0. $C_{34}H_{38}O_4N_4Cu$ requires C, 64·8; H, 6·0; N, 8·9; Cu, 10·1%).

(*c*) (i) A hot solution of cupric acetate (1 g.) in pyridine was added to one of *NN'*-di-*p*-nitrophenylformamidine (2·86 g.) in hot pyridine; a deep red colour developed. On the addition of methanolic potassium methoxide (5 c.c. of 2N) the colour changed to deep red-violet and crystals separated when the solution was kept for 12 hr. These were heated with pyridine (150 c.c.), and the solution was then filtered; blue-violet rhomboidal plates of *bis*-(NN'-*di*-p-*nitrophenylformamidine*)*tetrapyridinecopper* separated, which were red by transmitted light and lost 2 mols. of pyridine at 120° in 144 hr. [Found : Cu, 6·9; di-*p*-nitrophenylformamidine, 60·6; C_5H_5N, 31·5. $(C_{13}H_9O_4N_4)_2Cu(C_5H_5N)_4$ requires Cu, 6·7; di-*p*-nitrophenylformamidine, 60·0; C_5H_5N, 33·3. Loss on being heated, C_5H_5N, 16·4. Required : $2C_5H_5N$, 16·63%]. (ii) the same compound resulted when cuprous *NN'*-di-*p*-nitrophenylformamidine (1·5 g.) was refluxed for 15 min. with pyridine (150 c.c.). A suspension was formed and the whole was filtered. A yellow residue (0·6 g.) was obtained and a blue-green filtrate from which bis-(*NN'*-di-*p*-nitrophenylformamidine)tetrapyridinecopper separated (Found : Cu, 7·1; di-*p*-nitrophenylformamidine, 58·4; C_5H_5N, 32·1%).

Bis-(NN'-*di*-p-*nitrophenylformamidine*)*tetrapyridinenickel.*—In a similar preparation to (*c*) (i) but with anhydrous nickel acetate (0·86 g.), the corresponding *nickel compound* resulted. Repeated crystallisation from pyridine gave hexagonal prisms which were deep blue-violet by reflected and ruby-red by transmitted light (Found : C, 56·4; H, 4·3; N, 17·9. $C_{44}H_{38}O_8N_{12}Ni$ requires C, 58·3; H, 4·0; N, 17·8%). This compound was readily decomposed by water, dilute

acid, or ammonia; pyridine was liberated on contact with dilute aqueous sodium hydroxide (Found : Ni, 6·4; C_5H_5N, 33·0; di-*p*-nitrophenylformamidine, 58·9. Calc. for $(C_{13}H_9O_4N_4)_2$. $Ni(C_5H_5N)_4$: Ni, 6·2; C_5H_5N, 33·5; di-*p*-nitrophenylformamidine, 60·5%].

Absorption Spectra.—See Table 5.

TABLE 5. *Absorption spectra* $\lambda_{max.}$ (mμ) ($10^{-4}\varepsilon$ in parentheses).

Compound	In dioxan	In benzene	In *cyclo*hexane
NN'-Diphenylformamidine	—	284 (1·95)	—
Cu(I) derivative	—	324 (1·67)	—
NN'-Di-*p*-*n*-butoxyphenylformamidine	294 (2·74)	296 (2·45)	291 (2·48)
Cu(I) derivative	256 (2·3), 317 (1·9)	318 (1·82)	256 (2·33), 315 (1·74)
Ag derivative	245 (1·25), 310 (1·88)	—	256 (1·65), 307 (1·75)

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130. o-*Mercapto-azo-compounds. Part X.* Reactions of Azobenzene-2-sulphenyl Bromide and its Derivatives with Malonic Acid, Acetone, and Acetophenone.*

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Azobenzene-2-sulphenyl bromide and its 2-nitro-, 4-nitro-, and 2-benzylthio-derivatives condense with malonic acid, acetone, or acetophenone to yield, in controlled conditions, the corresponding (2-arylazophenylthio)acetic acids (III), acetonyl 2-arylazophenyl sulphides (IV), and 2-arylazophenyl phenacyl sulphides (V), respectively. The tendency of these products to decompose in presence of acid to the corresponding arylamines and benzothiazole-2-carboxylic acid (VI), 2-benzothiazolyl methyl ketone (VII), and 2-benzothiazolyl phenyl ketone (VIII) respectively, offering a novel route for the preparation of benzothiazole derivatives, is discussed.

SULPHENYL CHLORIDES and thiocyanates are known to condense with acetone, acetophenone, or ethyl acetoacetate to form the corresponding sulphides (I).[1] On the other hand, no similar reactions with sulphenyl bromides have been reported. Anthraquinone-1-sulphenyl bromide (like its chloride) does not react with the above-mentioned ketones,[2] whereas 3-nitrotoluene-4-sulphenyl bromide with acetone[3] and 2-nitrobenzenesulphenyl bromide with acetophenone[4] yield acetonyl bromide and phenacyl bromide respectively, in addition to the corresponding disulphides. Similarly, fluorenone-1-sulphenyl bromide, when heated with acetone, is converted into the disulphide, condensation not being observed.[5]

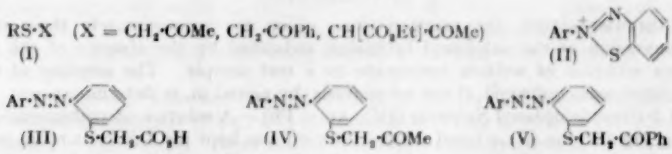
The water-solubility and exceptional stability to heat and hydrolysis of azobenzene-2-sulphenyl bromide and its derivatives, which is mainly due to their ability to exist as true salts involving 2-arylbenzo-1-thia-2 : 3-diazolium ions (II),[6] and the unexpected isolation of aniline hydrobromide (by Dr. C. E. Vellins in this laboratory) on heating azobenzene-2-sulphenyl bromide with acetone, suggested the present investigation.

At room temperature, azobenzene-2-sulphenyl bromide and its 2-nitro-, 4-nitro-, and 2-benzylthio-derivatives with malonic acid, acetone, or acetophenone in aqueous or

* Part IX, *J.*, 1956, 96.

[1] Zincke, *Ber.*, 1911, **44**, 769; Kharasch, Wehrmeister, and Tigermann, *J. Amer. Chem. Soc.*, 1947, **69**, 1612; for other references, see Kharasch, Potempa, and Wehrmeister, *Chem. Rev.*, 1946, **39**, 269.
[2] Fries and Schürmann, *Ber.*, 1919, **52**, 2170.
[3] Zincke and Rösc, *Annalen*, 1914, **406**, 103.
[4] Burawoy, Raymakers, and Turner, *J.*, 1955, 4491.
[5] Kharasch and Bruice, *J. Amer. Chem. Soc.*, 1951, **73**, 3240.
[6] Burawoy *et al.*, *J.*, 1954, 90, 4481; 1955, 3798; 1956, 90, 96.

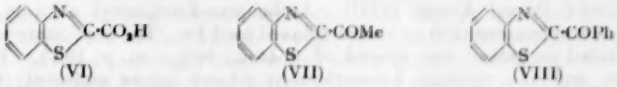
ethanolic solution slowly yield the corresponding (2-arylazophenylthio)acetic acids (III), acetonyl 2-arylazophenyl sulphides (IV), and 2-arylazophenyl phenacyl sulphides (V) respectively, the condensation with malonic acid being accompanied by partial decarboxylation.



(2-Phenylazophenylthio)acetic acid (III; Ar = Ph) could not be isolated, although the reaction was interrupted immediately after complete disappearance of azobenzene-2-sulphenyl bromide (indicated by the absence of the characteristic blue-violet colour due to sodium azobenzene-2-sulphenate on addition of sodium hydroxide to a test sample). Instead, aniline and benzothiazole-2-carboxylic acid (VI) are obtained which are formed by decomposition of the mercaptoacetic acid derivative, the latter reaction being, in this instance, apparently faster than the primary condensation.

Although (2-*p*-nitrophenylazophenylthio)acetic acid (III; Ar = *p*-$NO_2 \cdot C_6H_4$) can be isolated, it also undergoes ready dissociation to *p*-nitroaniline and benzothiazole-2-carboxylic acid, if the reaction mixture is kept for some time at room temperature. In contrast, (2-*o*-nitrophenylazophenylthio)- and (2-*o*-benzylthiophenylazophenylthio)-acetic acid (III; Ar = *o*-$NO_2 \cdot C_6H_4$ and *o*-$Ph \cdot CH_2 \cdot S \cdot C_6H_4$) are rather stable, no dissociation being observed even on prolonged heating of the solutions of the sulphenyl bromides with malonic acid or of the isolated acids in presence of a small amount of hydrochloric acid.

When solutions of azobenzene-2-sulphenyl bromide or its 4-nitro- or 2-benzylthio-derivative are heated with acetone or acetophenone, 2-benzothiazolyl methyl ketone (VII) or 2-benzothiazolyl phenyl ketone (VIII) is obtained in addition to aniline, *p*-nitroaniline, and *o*-benzylthioaniline, respectively. The corresponding sulphides (IV and V) are intermediates in these reactions, since heating their solutions (in acetone or benzene) with a small amount of hydrochloric acid yields the same products. The sulphides obtained from 2-nitroazobenzene-2′-sulphenyl bromide (IV and V; Ar = *o*-$NO_2 \cdot C_6H_4$) are much more stable and are recovered unchanged on prolonged heating of their solutions in presence of acid.



Benzothiazole-2-carboxylic acid (VI), which in the conditions of our experiments separates in an almost pure crystalline state, has been prepared by Hofmann [7] by hydrolysis of its amidine (obtained by the action of an excess of cyanogen on 2-aminothiophenol), and by Reissert [8] by the oxidation of sodium thio-oxanilate ($NHPh \cdot CS \cdot CO_2Na$) with potassium ferricyanide. These authors found that it cannot be readily purified by crystallisation, since it is easily decarboxylated, on heating, with formation of the liquid benzothiazole. Heating of azobenzene-2-sulphenyl bromide and of its 4-nitro-derivative with malonic acid in aqueous or ethanolic solution was, therefore, avoided. The carboxylic acid has been purified through its sparingly soluble stable sodium salt and further characterised as its stable ethyl ester, already obtained by Reissert.[8]

The action of 2-phenylazonaphthalene-1-sulphenyl bromide has also been investigated. However, it is recovered unchanged after prolonged heating with acetone or malonic acid in aqueous or ethanolic solution, condensation being apparently inhibited by steric hindrance.

A few experiments have been carried out with azobenzene-2-sulphenyl chloride and

[7] Hofmann, *Ber.*, 1887, **20**, 2257.
[8] Reissert, *Ber.*, 1904, **37**, 3731.

perchlorate. They behave similarly to the bromide, but the rate of reaction with hot acetone or acetophenone decreases considerably in the order chloride > bromide > perchlorate. This sequence, as well as the mechanism of the reactions, requires elucidation.

Experimental

If not otherwise stated, the reaction times given are approximately those required for complete conversion of the sulphenyl bromides, indicated by the absence of the blue colour developed on addition of sodium hydroxide to a test sample. The identity of the various products isolated was confirmed, if not by analysis, by mixed m. p. determinations.

Acetonyl 2-Phenylazophenyl Sulphide (IV; Ar = Ph).—A solution of azobenzene-2-sulphenyl bromide (1 g.) in acetone (5 c.c.) and water (100 c.c.) was kept for 7 days at room temperature. The precipitate of *acetonyl 2-phenylazophenyl sulphide* was filtered off, washed, and dried (0·85 g., 92%). Crystallisation from aqueous ethanol gave bright orange needles, m. p. 52° (Found : C, 66·7; H, 5·2; N, 10·4. $C_{15}H_{14}ON_2S$ requires C, 66·7; H, 5·2; N, 10·4%). Similar results were obtained with the chloride and perchlorate as starting material.

2-Benzothiazolyl Methyl Ketone (VII).—Azobenzene-2-sulphenyl chloride (1 g.), acetone (5 c.c.), and benzene (100 c.c.) were refluxed for 45 min. The precipitate of almost pure aniline hydrochloride was filtered off (0·35 g., 67%; m. p. 192°; Pinner [9] gives 192°; Ullmann [10] gives 198°). Aniline was identified by conversion into tribromoaniline. Concentration of the filtrate yielded *2-benzothiazolyl methyl ketone* (0·7 g., 90%). Crystallisation from aqueous ethanol or light petroleum (b. p. 60—80°) gave yellow needles, m. p. 109° (Found : C, 60·8; H, 4·1; N, 7·8. C_9H_7ONS requires C, 61·0; H, 3·9; N, 7·9%). Similar results were obtained with the bromide and perchlorate except that the reaction times were 10 and 20 hr., respectively, and on replacement of benzene by acetone as solvent.

Acetonyl 2-phenylazophenyl sulphide (0·5 g.), acetone (20 c.c.), and a drop of concentrated hydrochloric acid were refluxed for 1 hr. After partial removal of the acetone, water was added, and the precipitate of 2-benzothiazolyl methyl ketone was collected (0·25 g., 76%). Crystallisation as before gave yellow needles, m. p. 109°. On addition of bromine to the filtrate, tribromoaniline separated (0·45 g., 73%; m. p. 117°, from ethanol). When heated with acetone in absence of hydrochloric acid, the sulphide was recovered unchanged.

Phenacyl 2-Phenylazophenyl Sulphide (V; Ar = Ph).—A solution of azobenzene-2-sulphenyl bromide (0·5 g.) and acetophenone (5 c.c.) in ethanol (50 c.c.) was kept for about 3 months at room temperature. Water was added, and the precipitated *sulphide* filtered off (0·45 g., 80%). Crystallisation from aqueous ethanol gave orange needles, m. p. 140° (Found : C, 72·1; H, 5·0; N, 8·7. $C_{20}H_{16}ON_2S$ requires C, 72·2; H, 4·8; N, 8·4%). The sulphenyl chloride behaved similarly.

2-Benzothiazolyl Phenyl Ketone (VIII).—Azobenzene-2-sulphenyl chloride (1 g.), acetophenone (5 c.c.), and benzene (100 c.c.) were refluxed for 1 hr. The precipitate of aniline hydrochloride (identified as before) was filtered off (0·45 g., 90%; m. p. 192°). The filtrate was steam-distilled, and the residual *2-benzothiazolyl phenyl ketone* collected (0·75 g., 78%). Crystallisation from aqueous ethanol gave pale yellow needles, m. p. 99° (Found : C, 70·1; H, 3·8; N, 5·8. $C_{14}H_9ONS$ requires C, 70·3; H, 3·8; N, 5·9%). When the sulphenyl bromide was used (reaction time 14 hr.) aniline separated as hydrobromide, m. p. 278°.

Phenacyl 2-phenylazophenyl sulphide (0·2 g.), benzene (20 c.c.), and a drop of concentrated hydrochloric acid were refluxed for 2 hr. After removal of benzene and addition of water, the precipitate of 2-benzothiazolyl phenyl ketone (0·1 g., 70%; m. p. 99°, from dilute ethanol) was collected. The mother-liquor contained aniline. In absence of hydrochloric acid, unchanged sulphide was recovered quantitatively.

Benzothiazole-2-carboxylic Acid (VI).—A solution of azobenzene-2-sulphenyl bromide (1 g.) and malonic acid (1 g.) in water (110 c.c.) was kept at room temperature for 3 days. Benzothiazole-2-carboxylic acid separated as white needles, m. p. 105° (0·6 g., 83%). It was purified *via* its sparingly soluble sodium salt, and obtained as needles, m. p. 108° (Hofmann [7] and Reissert [8] give 108°) (Found : C, 53·4; H, 3·2; N, 7·0. Calc. for $C_8H_5O_2NS$: C, 53·6; H, 2·8; N, 7·8%). It was also characterised as its ethyl ester, needles (from ethanol), m. p. 70° (Reissert [8] gives 70—71°) (Found : C, 58·3; H, 4·3; N, 7·1. Calc. for $C_{10}H_9O_2NS$: C, 58·0; H, 4·3; N, 6·8%). On addition of bromine to the mother-liquor, tribromoaniline separated (1 g., 80%; m. p. 117°, from ethanol). The sulphenyl chloride and perchlorate behaved similarly.

[9] Pinner, *Ber.*, 1881, **14**, 1083.
[10] Ullmann, *Ber.*, 1898, **31**, 1699.

Acetonyl 2-o-*Nitrophenylazophenyl Sulphide* (IV; Ar = o-NO_2·C_6H_4).—A solution of 2-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) and acetone (5 c.c.) in water (500 c.c.) was kept for 24 hr. at room temperature. The precipitated *sulphide* was filtered off (0·45 g., 96%). Crystallisation from light petroleum (b. p. 60—80°) or aqueous ethanol gave orange needles, m. p. 115—116° (Found: C, 57·2; H, 4·0; N, 13·4. $C_{18}H_{13}O_3N_3S$ requires C, 57·2; H, 4·1; N, 13·3%). Replacement of the water by benzene (100 c.c.) and 30 hours' refluxing gave the same sulphide (0·3 g., 64%; m. p. 115—116°, from light petroleum) after removal of solvents. The sulphide was recovered unchanged after being heated in acetone with a drop of concentrated hydrochloric acid for 2 hr.

2-o-*Nitrophenylazophenyl Phenacyl Sulphide* (V; Ar = o-NO_2·C_6H_4).—A solution of 2-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) and acetophenone (5 c.c.) in ethanol (100 c.c.) was kept at room temperature for 7 days. After addition of water, the precipitate of 2-o-*nitrophenylazophenyl phenacyl sulphide* was filtered off (0·4 g., 71%). Crystallisation from aqueous ethanol gave orange needles, m. p. 121° (Found: C, 63·7; H, 4·2; N, 11·4. $C_{20}H_{15}O_3N_3S$ requires C, 63·7; H, 4·0; N, 11·2%). Replacement of the ethanol by benzene (100 c.c.) and 40 hours' refluxing, followed by removal of the solvent and unchanged acetophenone by steam-distillation, afforded the same sulphide (0·35 g., 62%; m. p. 121°, from aqueous ethanol).

(2-o-*Nitrophenylazophenylthio*)*acetic Acid* (III; Ar = o-NO_2·C_6H_4).—A solution of 2-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) and malonic acid (0·5 g.) in water (500 c.c.) was kept at room temperature for 2 days. The precipitated *acid* was collected (0·4 g., 85%). Crystallisation from benzene–light petroleum (b. p. 60—80°) gave a yellow powder, m. p. 168—169° (Found: C, 53·2; H, 3·3; N, 13·4. $C_{14}H_{11}O_4N_3S$ requires C, 53·0; H, 3·4; N, 13·2%). A similar result was obtained on refluxing the same solution for 2 hr. The product was recovered unchanged after its benzene solution had been refluxed with a drop of concentrated hydrochloric acid for 5 hr.

Acetonyl 2-p-*Nitrophenylazophenyl Sulphide* (IV; Ar = p-NO_2·C_6H_4).—A solution of 4-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) and acetone (5 c.c.) in water (500 c.c.) was kept at room temperature for 3 days. The precipitated *sulphide* was collected (0·45 g., 96%). Crystallisation from methanol gave orange needles, m. p. 144° (Found: C, 57·1; H, 4·0; N, 13·6. $C_{18}H_{13}O_3N_3S$ requires C, 57·1; H, 4·1; N, 13·3%).

Decomposition of Acetonyl 2-p-*Nitrophenylazophenyl Sulphide.*—4-Nitroazobenzene-2′-sulphenyl bromide (1 g.), acetone (10 c.c.), and benzene (150 c.c.) were refluxed for 8 hr. After removal of the solvent, the residue was extracted with dilute hydrochloric acid, and the insoluble 2-benzothiazolyl methyl ketone collected (0·3 g., 57%; m. p. 109°, from aqueous ethanol). The acidic extract was neutralised with aqueous sodium hydroxide, and the precipitate of *p*-nitroaniline filtered off (0·25 g., 61%; m. p. 147°, from water).

Acetonyl 2-*p*-nitrophenylazophenyl sulphide (0·5 g.), acetone (20 c.c.), and a drop of concentrated hydrochloric acid were refluxed for 1 hr. The solution was worked up as above, yielding 2-benzothiadiazolyl methyl ketone (0·2 g., 71%) and *p*-nitroaniline (0·15 g., 70%). The sulphide was recovered unchanged when heated with acetone in absence of hydrochloric acid.

2-p-*Nitrophenylazophenyl Phenacyl Sulphide* (V; Ar = p-NO_2·C_6H_4).—A solution of 4-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) and acetophenone (5 c.c.) in ethanol (100 c.c.) was kept at room temperature for 15 days. Addition of water precipitated the *sulphide*, which was filtered off (0·4 g., 71%). Crystallisation from benzene–light petroleum (b. p. 60—80°) gave orange needles, m. p. 171° (Found: C, 64·2; H, 3·8; N, 11·4. $C_{20}H_{15}O_3N_3S$ requires C, 63·7; H, 4·0; N, 11·2%).

Decomposition of 2-p-*Nitrophenylazophenyl Phenacyl Sulphide.*—4-Nitroazobenzene-2′-sulphenyl bromide (0·5 g.), acetophenone (5 c.c.), and benzene (100 c.c.) were refluxed for 20 hr. Benzene and unchanged acetophenone were removed by steam-distillation, and, after cooling, the insoluble 2-benzothiazolyl phenyl ketone was filtered off (0·2 g., 57%; m. p. 99°, from aqueous ethanol). The filtrate was concentrated, yielding *p*-nitroaniline (0·1 g., 55%; m. p. 147°, from water). A similar result was obtained on refluxing 2-*p*-nitrophenylazophenyl phenacyl sulphide (0·2 g.) in benzene (20 c.c.) with a drop of concentrated hydrochloric acid for 2 hr. When heated without the acid, the sulphide was recovered unchanged.

(2-p-*Nitrophenylazophenylthio*)*acetic Acid* (III; Ar = p-NO_2·C_6H_4).—A solution of 4-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) and malonic acid (0·5 g.) in water (500 c.c.) was kept for 2 days at room temperature. The precipitated *acid* was collected (0·2 g., 43%). Crystallisation from benzene–light petroleum (b. p. 60—80°) gave a yellow powder, m. p. 170° (Found: C, 53·6; H, 3·2; N, 13·6. $C_{14}H_{11}O_4N_3S$ requires C, 53·0; H, 3·4; N, 13·2%).

Decomposition. The preceding experiment was repeated, but, after complete disappearance

of the sulphenyl bromide, the solution was kept for another 5 days at room temperature. The yellow precipitate disappeared slowly, being replaced by white needles of benzothiazole-2-carboxylic acid which were filtered off (0·03 g., 11%; m. p. 106—107°). The filtrate was concentrated and neutralised with sodium hydroxide, and the precipitate of almost pure *p*-nitroaniline collected (0·16 g., 78%; m. p. 146°).

Acetonyl 2-o-Benzylthiophenylazophenyl Sulphide (IV; Ar = *o*-Ph·CH_2·S·C_6H_4).—A solution of 2-benzylthioazobenzene-2′-sulphenyl bromide (0·5 g.) and acetone (10 c.c.) in ethanol (50 c.c.) was kept at room temperature for 24 hr. Water was added, and the precipitated *sulphide* was filtered off (0·4 g., 83%). Crystallisation from ethanol gave orange needles, m. p. 129° (Found: C, 67·3; H, 5·2; N, 7·4. $C_{22}H_{20}ON_2S_2$ requires C, 67·3; H, 5·1; N, 7·1%).

Decomposition. The preceding experiment was repeated, but, after disappearance of the sulphenyl bromide, the solution was heated for 10 min. at 60° and kept for another 24 hr. at room temperature. The solution was concentrated under reduced pressure, water and dilute hydrochloric acid were added, and the mixture was extracted with ether, from which 2-benzothiazolyl methyl ketone was obtained (0·1 g., 47%; m. p. 109°, from aqueous ethanol). The aqueous layer was made alkaline and extracted with ether. Evaporation of the solvent yielded *o*-benzylthioaniline (0·17 g., 65%; m. p. 46°, from light petroleum).

2-o-Benzylthiophenylazophenyl Phenacyl Sulphide (V; Ar = *o*-Ph·CH_2·S·C_6H_4).—A solution of 2-benzylthioazobenzene-2′-sulphenyl bromide (0·5 g.) and acetophenone (5 c.c.) in ethanol (50 c.c.) was kept at room temperature for 2 days. The precipitated *sulphide* was collected (0·4 g., 73%). Crystallisation from ethanol gave orange needles, m. p. 147° (Found: C, 71·5; H, 4·8; N, 5·5. $C_{27}H_{22}ON_2S_2$ requires C, 71·4; H, 4·8; N, 6·1%).

Decomposition of the sulphide. A solution of 2-benzylthioazobenzene-2′-sulphenyl bromide (0·5 g.) and acetophenone (5 c.c.) in benzene (100 c.c.) was refluxed for 14 hr., cooled, and extracted with dilute hydrochloric acid. The extract was neutralised, and the precipitate of *o*-benzylthioaniline collected (0·12 g., 46%; m. p. 46°, from light petroleum). The benzene layer was steam-distilled, and the residual insoluble 2-benzothiazolyl phenyl ketone was filtered off (0·14 g., 44%; m. p. 99°, from aqueous ethanol).

(2-o-Benzylthiophenylazophenylthio)acetic Acid (VI; Ar = *o*-Ph·CH_2·S·C_6H_4).—A solution of 2-benzylthioazobenzene-2′-sulphenyl bromide (0·5 g.) and malonic acid (0·5 g.) in water (10 c.c.) and ethanol (100 c.c.) was kept at room temperature for 24 hr. The precipitated *acid* was filtered off (0·35 g., 73%). Crystallisation from benzene or ethanol gave a yellow powder, m. p. 158° (Found: C, 63·7; H, 4·8; N, 7·6. $C_{21}H_{18}O_2N_2S_2$ requires C, 63·9; H, 4·5; N, 7·1%). The preceding experiment was repeated, but the solution refluxed for 1 hr. On cooling, the almost pure mercaptoacetic acid derivative separated (0·41 g., 85%; m. p. 158°).

The product (0·2 g.), benzene (20 c.c.), and a drop of concentrated hydrochloric acid were refluxed for 5 hr. Unchanged starting material was recovered almost quantitatively.

Methyl ester. A solution of the mercaptoacetic acid derivative (0·2 g.) and diazomethane (~0·2 g.) in ether (60 c.c.) was kept for 20 hr. and then concentrated to a small volume. Addition of light petroleum precipitated the *ester* (0·17 g., 82%). Crystallisation from methanol gave orange-yellow needles, m. p. 128° (Found: C, 65·1; H, 5·1. $C_{22}H_{20}O_2N_2S_2$ requires C, 64·7; H, 4·9%).

Attempted Condensation of 2-Phenylazonaphthalene-1-sulphenyl Bromide with Acetone or Malonic Acid.—Solutions of the sulphenyl bromide (0·5 g.) and acetone (10 c.c.) or malonic acid (1 g.) in water (100 c.c.) were kept at room temperature for 3 months or refluxed for 20—30 hr. Unchanged starting material was recovered almost quantitatively. The same result was obtained when the water was replaced by acetone or benzene.

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College of Technology, University of Manchester. [*Received, September 23rd*, 1955.]

131. o-*Mercapto-azo-compounds. Part XI.* Action of Alkali on Azobenzene-2-sulphenyl Bromide and its Derivatives.*

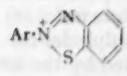
By A. Burawoy and A. Chaudhuri.

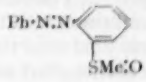
The action of aqueous sodium hydrogen carbonate, aqueous sodium hydroxide, and (wet) liquid ammonia on azobenzene-2-sulphenyl bromide and its derivatives is investigated. According to conditions, the corresponding disulphides and either disulphoxides (reaction 1) or sulphinates (3) are formed. The preparation of the disulphoxides from the corresponding sulphenyl bromides and sodium sulphinates in water is described. The reactions of 2-phenylazonaphthalene-1-sulphenyl bromide with alkalis are complicated by the tendency of di-(2-phenylazo-1-naphthyl) disulphoxide (III) to decompose readily into di-(2-phenylazo-1-naphthyl) sulphide (IV) and sulphur dioxide.

Zincke and Farr [1] found that *o*-nitrobenzenesulphenyl chloride forms with 2 mol. of sodium hydroxide the corresponding disulphide and disulphoxide, and that with an excess of sodium hydroxide the disulphoxide is then converted into more disulphide and the sodium sulphinate. They also observed that the latter reaction, now recognised to be characteristic of all sulphenyl halides and thiocyanates,[2] is accompanied by the transient appearance of a blue colour attributed to the sodium sulphenate formed as an intermediate.

As recently shown,[3,4,5] azobenzene-2-sulphenyl bromide and its *o*-nitro-, *p*-nitro-, and *o*-benzylthio-derivatives in aqueous or ethanolic solutions, in which they exist as true salts involving 2-arylbenzo-1-thia-2 : 3-diazolium ions (I), similarly form on addition of excess of sodium hydroxide the soluble blue-violet or blue sodium sulphenates, which cannot be isolated but have been identified by conversion into the stable 2-arylazophenyl methyl sulphoxides on rapid treatment with methyl sulphate. The formation of the parent methyl *o*-phenylazophenyl sulphoxide (II), not yet reported, is described on p. 656.

The blue colour of the solutions disappears slowly, the sulphenates being replaced by the corresponding disulphides and sodium sulphinates. In order to obtain further information about the action of alkali on these sulphenyl bromides, the effect of stoicheiometric quantities and of weaker alkalis has been investigated. Addition of slightly more than

(I) 

 (II)

1 mol. of sodium hydrogen carbonate or sodium hydroxide to an aqueous solution of azobenzene-2-sulphenyl bromide quickly yields a precipitate of di-(*o*-phenylazophenyl) disulphide and disulphoxide according to equation (1); this mixture can be quantitatively separated by chromatography with a benzene solution and a silica gel column.

With 1·75 mol. of sodium hydroxide the disulphoxide, initially formed, is converted into more disulphide and the sodium azobenzene-2-sulphinate according to (2). The total

(1) $12ArSBr + 12NaOH = 3ArS{\cdot}SAr + 3ArSO_2{\cdot}SAr + 12NaBr + 6H_2O$
(2) $3ArSO_2{\cdot}SAr + 4NaOH = ArS{\cdot}SAr + 4ArSO_2^-Na^+ + 2H_2O$
(3) $12ArSBr + 16NaOH = 4ArS{\cdot}SAr + 4ArSO_2^-Na^+ + 12NaBr + 8H_2O$

result (3) is similar to that already [3] reported for the action of a great excess of sodium hydroxide, but in these less alkaline conditions no, or only a very transient, blue-violet

* Part X, preceding paper.

[1] Zincke and Farr, *Annalen*, 1912, **391**, 55.
[2] Kharasch, Potempa, and Wehrmeister, *Chem. Rev.*, 1946, **39**, 269.
[3] Burawoy and Vellins, *J.*, 1954, 90.
[4] Burawoy, Chaudhuri, and Vellins, *J.*, 1955, 3798.
[5] *Idem*, *J.*, 1956, 90.

colour of the sodium azobenzene-2-sulphenate (appearing sometimes on contact of the drops of sodium hydroxide with the solution) is observed and the reaction is much faster, indicating that the disproportionation is a property of the undissociated sulphenic acid and not of the sulphenate ion, the instability of which is only apparent, being due to partial hydrolysis.

Di-(*o*-phenylazophenyl) disulphoxide has been identified by its unambiguous preparation from azobenzene-2-sulphenyl bromide and sodium azobenzene-2-sulphinate in aqueous solution. The solubility and stability of the sulphenyl bromide in water allow this simplification of the usual method for the preparation of disulphoxides, the reaction of a silver sulphinate with a sulphenyl halide in ether solution, first used by Zincke and Farr [1] for the preparation of di-(*o*-nitrophenyl) disulphoxide. Di-(*o*-phenylazophenyl) disulphoxide is sparingly soluble in water and forms with 1 equiv. of sodium hydroxide in aqueous suspension, or more slowly with a considerable excess of sodium hydroxide in dilute methanol, the disulphide and the sodium sulphinate according to (2). In the latter case, however, the reaction is preceded by development of the rather persistent blue-violet colour of the sodium sulphenate.

The action of liquid ammonia below —50° on azobenzene-2-sulphenyl bromide has also been investigated, the original aim having been the preparation of azobenzene-2-sulphenamide. This is not formed, but the small amount of water present in commercial liquid ammonia rapidly converts the sulphenyl bromide into the disulphide and the disulphoxide (as 1). If the reaction is allowed to proceed for a longer time (until a test sample, on addition of sodium hydroxide, failed to show the blue-violet colour characteristic of the sodium sulphenate, indicating complete disappearance of the disulphoxide), the disulphoxide is further converted into more disulphide and the ammonium sulphinate (as 2). The same result is obtained with the disulphoxide as starting material. The blue-violet colour of the sulphenate ion is not observed at any stage in these experiments.

2-Nitro-, 4-nitro-, and 2-benzylthio-azobenzene-2′-sulphenyl bromides behave like the parent substance, except that the disulphoxides, all of which have been also synthesised from the corresponding sulphenyl bromides and sodium sulphinates, are completely insoluble in water, and in aqueous suspension are not affected at room temperature by an equimolecular amount and only slightly by a great excess of sodium hydroxide.

These observations show that the action of alkali on azobenzene-2-sulphenyl bromide and its derivatives (and probably on other sulphenyl halides or thiocyanates) can proceed in at least three stages : (i) Formation of the sulphenic acid (which, with an excess of sodium hydroxide, is in equilibrium with the coloured sodium sulphenate) (4). (ii) Disproportionation of the sulphenic acid into the disulphoxide and disulphide, the mechanism of which requires further elucidation, but which is probably initiated by the intermediate formation of the sulphenic anhydride (5). (iii) Cleavage of the disulphoxide into the sulphinate and the sulphenic acid (being, again, with an excess of sodium hydroxide in equilibrium with the blue sodium sulphenate) (6) which re-enters the reaction cycle.

(4) $ArSBr \longrightarrow ArS{\cdot}OH$

(5) $4ArS{\cdot}OH \longrightarrow (2ArSO{\cdot}SAr) \longrightarrow ArSO_2{\cdot}SAr + ArS{\cdot}SAr$

(6) $ArSO_2{\cdot}SAr \longrightarrow ArSO_2^-Na^+(NH_4^+) + Ar{\cdot}S{\cdot}OH$

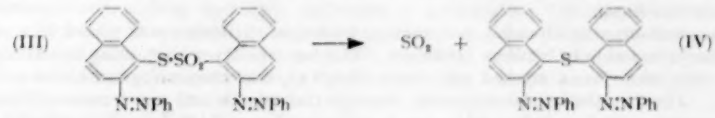
The action of alkali on 2-phenylazonaphthalene-1-sulphenyl bromide is complicated by the instability of di-(2-phenylazo-1-naphthyl) disulphoxide (III). This separates when aqueous solutions of the sulphenyl bromide and the sodium sulphinate are mixed, and, if quickly filtered off, is obtained almost pure, but it cannot be crystallised, since on standing either as solid or in solution, it decomposes at room temperature, and more rapidly on heating, into di-(2-phenylazo-1-naphthyl) sulphide (IV) and sulphur dioxide. This is similar to the tendency [6] of 2-phenylazonaphthalene-1-sulphinic acid to decompose into 2-phenylazonaphthalene and sulphur dioxide.

2-Phenylazonaphthalene-1-sulphenyl bromide in aqueous solution with 1 mol. of sodium hydroxide instantaneously forms a mixture of the disulphide and the unstable disulphoxide

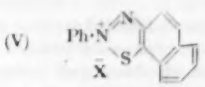
[6] Burawoy, Chaudhuri, and Hyslop, *J.*, 1956, 96.

(and/or monosulphide) which are separated and isolated most economically by reduction of the disulphide with sodium sulphide to the water-soluble sodium mercaptide. The latter, after separation of the insoluble monosulphide, readily yields the disulphide in air.[6]

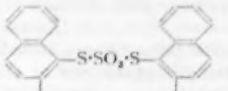
In contrast, the reaction is very slow with 1 mol. of sodium hydrogen carbonate, the solution remaining clear for about 2 hr. This can only be attributed to the presence in solution of 2-phenylnaphtho(1′ : 2′ : 5 : 4)-1-thia-2 : 3-diazolium hydrogen carbonate (V) and to the greater basicity of 2-phenylazonaphthalene-1-sulphenic acid than of azobenzene-



2-sulphenic acid and its derivatives (see also below). Moreover, the reaction remains incomplete, since the sulphur dioxide, liberated by decomposition of the disulphoxide formed, increases the acidity of the solution and finally inhibits hydrolysis. A small amount of the 2-phenylnaphthothiadiazolium sulphite (V) or its covalent isomer 2-phenylazonaphthalene-1-sulphenyl sulphite (VI) is also precipitated, together with the disulphide and monosulphide. It has been identified with an authentic sulphite prepared from the sulphenyl bromide by double decomposition with sodium sulphite.



(X = HCO_3 or $\frac{1}{2}SO_3$)



Treatment of the sulphenyl bromide with liquid ammonia quickly gives a mixture of the disulphide and the monosulphide, but no sulphinic acid. The result is the same if the solution is allowed to stand. This indicates that in these weakly alkaline conditions the decomposition of the disulphoxide to the monosulphide is faster than cleavage to the sulphinate and the sulphenic acid (as 6).

On the other hand, as already shown,[6] an appreciable excess of sodium hydroxide converts the sulphenyl bromide in water almost instantaneously into the disulphide and sodium sulphinate. In these strongly alkaline conditions cleavage of the disulphoxide, initially formed, is very fast and takes preference over decomposition. The rapidity of this reaction and the non-appearance of the blue colour of the sulphenate ion, which is in contrast to the behaviour of azobenzene-2-sulphenyl bromide and its substituted derivatives,[3, 4, 5] indicates an appreciably lower acidity of the 2-phenylazonaphthalene-1-sulphenic acid in agreement with the greater basicity of this amphoteric compound as indicated by the stability of its hydrogen carbonate (cf. above).

Experimental

Di-(o-phenylazophenyl) Disulphoxide.—An aqueous solution of sodium azobenzene-2-sulphinate (0·2 g. in 20 c.c.) was added to azobenzene-2-sulphenyl bromide (0·2 g.) in water (60 c.c.). The *disulphoxide* separated immediately (0·3 g., 91%). Crystallisation from light petroleum (b. p. 60—80°) gave orange needles, m. p. 103—104° (Found: C, 62·8; H, 3·8; N, 12·1. $C_{24}H_{18}O_2N_4S_2$ requires C, 62·8; H, 3·9; N, 12·2%). The disulphoxide is slightly soluble in water, and when stirred in aqueous suspension with an equivalent amount of sodium hydroxide is readily converted into the disulphide and sodium azobenzene-2-sulphinate.

Action of Sodium Hydrogen Carbonate or Hydroxide (1 Mol.) on Azobenzene-2-sulphenyl Bromide.—Sodium hydrogen carbonate (0·01N; 350 c.c., ~1 mol.) was added slowly to a well-stirred aqueous solution of azobenzene-2-sulphenyl bromide (1 g. in 200 c.c.). At no stage was the blue-violet colour characteristic of sodium azobenzene-2-sulphenate observed. After a few hours, the precipitate of di-(*o*-phenylazophenyl) disulphide and disulphoxide was filtered off (0·7 g.). The disulphoxide was extracted with cold methanol and the insoluble disulphide

collected (0·3 g., 84%). Crystallisation from light petroleum (b. p. 60—80°) gave orange needles, m. p. and mixed m. p. 142° (Burawoy and Vellins [3] give 142°) The disulphoxide was isolated from the methanol extract and from an ether extract of the original aqueous filtrate (0·3 g., 78%; m. p. and mixed m. p. 103—104°, from light petroleum).

A similar result was obtained with sodium hydroxide (0·01N; 350 c.c., ~1 mol.), except that a very transient appearance of the blue-violet colour could not be avoided in the last stages of the addition on contact of the sodium hydroxide with the solution, and that a very small amount of azobenzene-2-sulphinic acid (<0·05 g.) was also formed and isolated from the acidified original mother-liquor.

The experiment was repeated, but sodium hydrogen carbonate was added to a solution of the sulphenyl bromide in benzene (200 c.c.). The benzene layer containing the disulphide and disulphoxide, after being washed and dried (Na_2SO_4), was chromatographed on a column of silica gel. The disulphide passed quickly through the column and was recovered (almost pure) from the benzene solution (0·3 g., 84%; m. p. and mixed m. p. 142°, from light petroleum). The disulphoxide, adsorbed at the top of the column, was eluted with chloroform (0·3 g., 78%; m. p. and mixed m. p. 103—104°, from light petroleum). The separation is quantitative.

Action of Sodium Hydroxide (1·75 *Mol.*) *on Azobenzene-2-sulphenyl Bromide.*—Aqueous sodium hydroxide (0·01N; 600 c.c., 1·75 mol.) was added slowly to a well-stirred solution of the sulphenyl bromide (1 g.) in water (200 c.c.). The disulphide was quickly precipitated and was filtered off (0·45 g., 91%; m. p. and mixed m. p. 142°, from light petroleum). The filtrate was acidified with hydrochloric acid and extracted with ether which, on evaporation, yielded azobenzene-2-sulphinic acid (0·2 g., 74%; m. p. and mixed m. p. 104°, from dilute methanol; Burawoy and Vellins [3] give 104°).

Action of Sodium Hydroxide (*Excess*) *on Di-*(*o-phenylazophenyl*) *Disulphoxide.*—10% Aqueous sodium hydroxide (20 c.c.) was added to a solution of the disulphoxide (0·5 g.) in methanol (100 c.c.). After disappearance of the blue-violet colour which developed immediately, the precipitated disulphide was filtered off (0·15 g., 96%; m. p. and mixed m. p. 142°, from light petroleum). The filtrate was diluted with water and acidified with hydrochloric acid. The precipitate of azobenzene-2-sulphinic acid was collected (0·25 g., 70%; m. p. and mixed m. p. 104°, from aqueous methanol).

Methyl 2-Phenylazophenyl Sulphoxide.—40% Aqueous sodium hydroxide (5 c.c.) was added to a solution of azobenzene-2-sulphenyl bromide (0·5 g.) in methanol (50 c.c.). The blue-violet solution was immediately shaken with methyl sulphate (3 c.c.) until the blue colour had disappeared. Water was added and the precipitate of *methyl 2-phenylazophenyl sulphoxide* was filtered off (0·3 g., 72%). Crystallisation from aqueous methanol gave orange-yellow needles, m. p. 58—59° (Found: C, 64·3; H, 5·1; N, 11·4. $C_{13}H_{12}ON_2S$ requires C, 63·9; H, 4·9; N, 11·3%).

Di-o-(*2-nitrophenylazophenyl*) *Disulphoxide.*—Sodium 2-nitroazobenzene-2′-sulphinate (0·5 g.) in water (50 c.c.) was added to 2-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) in water (500 c.c.). The *disulphoxide* separated immediately (0·8 g., 98%). Crystallisation from benzene gave reddish-brown prisms, m. p. 198° (Found: C, 52·4; H, 2·9; N, 15·8. $C_{24}H_{16}O_6N_6S_2$ requires C, 52·6; H, 2·9; N, 15·6%). The disulphoxide is insoluble in water and its suspension is only very slowly, if at all, affected even by an excess of aqueous sodium hydroxide.

Action of Sodium Hydrogen Carbonate or Hydroxide (1 *Mol.*) *on 2-Nitroazobenzene-2′-sulphenyl Bromide.*—Aqueous sodium hydrogen carbonate or sodium hydroxide (0·01N; 150 c.c., ~1 mol.) was added slowly to a well-stirred suspension of the sulphenyl bromide (0·5 g.) in water (300 c.c.). No blue colour developed. The precipitate of di-(*o*-2-nitrophenylazophenyl) disulphide and disulphoxide, formed instantaneously, was filtered off (0·35 g.). The mixture was quantitatively separated chromatographically by means of benzene and a column of silica gel. The disulphide (0·15 g., 79%) crystallised from benzene as yellow needles, m. p. and m. p. 172—173° (Burawoy, Chaudhuri, and Vellins [5] give 172—173°). The disulphoxide was eluted with chloroform (0·15 g., 75%; m. p. and mixed m. p. 198°, from benzene). The same result was obtained with 2 mol. of sodium hydroxide, no sulphinic acid being formed.

Action of Sodium Hydroxide (*Excess*) *on Di-*(*o-2-nitrophenylazophenyl*) *Disulphoxide.*—10% Aqueous sodium hydroxide (20 c.c.) was added to the disulphoxide (0·5 g.) in methanol (100 c.c.). The solution was kept until disappearance of the deep blue colour which developed immediately. The precipitate of the disulphide was filtered off (0·14 g., 90%; m. p. and mixed m. p. 172—173°, from benzene). The filtrate was diluted with water and acidified. The precipitate of 2-nitroazobenzene-2′-sulphinic acid was collected (0·25 g., 70%; m. p. and mixed m. p. 144—145°, from aqueous methanol; Burawoy, Chaudhuri, and Vellins [5] give 144—145°).

Di-(o-4-nitrophenylazophenyl) Disulphoxide.—Sodium 4-nitroazobenzene-2′-sulphinate (0·5 g.) in water (50 c.c.) was added to 4-nitroazobenzene-2′-sulphenyl bromide (0·5 g.) in water (300 c.c.). The almost quantitative precipitate of the *disulphoxide* (0·8 g.) crystallised from benzene and light petroleum (b. p. 60—80°) as reddish-brown prisms, m. p. 172° (Found: C, 53·0; H, 2·9; N, 15·6. $C_{24}H_{14}O_6N_6S_2$ requires C, 52·6; H, 2·9; N, 15·6%), insoluble in water and, in suspension, only very slowly attacked by an excess of sodium hydroxide.

Action of Sodium Hydrogen Carbonate or Hydroxide (1 Mol.) on 4-Nitroazobenzene-2′-sulphenyl Bromide.—A suspension of the bromide (0·5 g.) in water (500 c.c.) was treated, as described for the 2-nitro-isomer, with sodium hydrogen carbonate or hydroxide. The disulphide (0·15 g., 79%; m. p. and mixed m. p. 228°, from benzene; Burawoy, Chaudhuri, and Vellins [5] give 228°) and the disulphoxide (0·15 g., 75%; m. p. and mixed m. p. 172°, from benzene and light petroleum) were isolated after quantitative chromatographic separation. No sulphinic acid was formed. The same result was obtained with 2 mol. of sodium hydroxide.

Action of Sodium Hydroxide (Excess) on Di-(o-4-nitrophenylazophenyl) Disulphoxide.—A solution of the disulphoxide (0·5 g.) in methanol (100 c.c.) was treated with sodium hydroxide, as described for the 2-nitro-isomer. The disulphide (m. p. and mixed m. p. 228°, from benzene) and the sulphinic acid (m. p. and mixed m. p. 133°, from methanol; Burawoy, Chaudhuri, and Vellins [5] give 133°) were obtained in similar yields.

Di-(o-2-benzylthiophenylazophenyl) Disulphoxide.—Solutions of sodium 2-benzylthioazobenzene-2′-sulphinate (0·5 g.) in water (50 c.c.) and of 2-benzylthioazobenzene-2′-sulphenyl bromide (0·5 g.) in ethanol (100 c.c.) were mixed, and the precipitated *disulphoxide* (0·6 g., 71%) crystallised from ethanol as reddish-brown needles, m. p. 135° (Found: C, 64·8; H, 4·1; N, 8·4. $C_{38}H_{30}O_2N_4S_4$ requires C, 65·0; H, 4·3; N, 8·0%), insoluble in water and, in aqueous suspension, not attacked by sodium hydroxide at room temperature.

Action of Sodium Hydrogen Carbonate or Hydroxide (1 Mol.) on 2-Benzylthioazobenzene-2′-sulphenyl Bromide.—A suspension of the sulphenyl bromide (0·5 g.) in 10% aqueous ethanol (400 c.c.) was treated, as described for the nitro-derivatives, with sodium hydrogen carbonate or hydroxide (0·01N; 121 c.c., ~1 mol.). The disulphide (0·15 g., 75%; m. p. and mixed m. p. 231°, from benzene; Burawoy, Chaudhuri, and Vellins [4] give 231°) and the disulphoxide (0·15 g., 65%; m. p. and mixed m. p. 135°, from ethanol) were isolated after chromatographic separation. No sulphinic acid was formed.

Action of Sodium Hydroxide (Excess) on Di-(o-2-benzylthiophenylazophenyl) Disulphoxide.—10% Aqueous sodium hydroxide (20 c.c.) was added to a methanolic solution of the disulphoxide (0·5 g. in 100 c.c.). After disappearance of the blue colour, the disulphide (m. p. and mixed m. p. 231°, from benzene) and the sulphinic acid (m. p. and mixed m. p. 126°, from ethanol; Burawoy, Chaudhuri, and Vellins [4] give m. p. 126°) were isolated.

Action of (Wet) Liquid Ammonia on Azobenzene-2-sulphenyl Bromide, Di-(o-phenylazophenyl) Disulphoxide, and their Derivatives.—(i) Azobenzene-2-sulphenyl bromide or its 2-nitro- or 4-nitro- or 2-benzylthio-derivative (0·5 g.) was added to well-stirred liquid ammona (30—50 c.c.) below −50°. After 30 min., ammonia was evaporated off. The residue, consisting of the corresponding disulphide (75—85%) and disulphoxide (66—78%), was separated chromatographically as described earlier.

(ii) The experiments were repeated, but the reaction allowed to proceed for 12—30 hr., until a test sample failed to develop a blue colour with ethanolic sodium hydroxide, showing complete disappearance of the disulphoxide formed initially. After evaporation of the ammonia, the residue was extracted with water or dilute aqueous sodium hydroxide, and the residual insoluble disulphide was collected (70—80%). On acidification of the alkaline extracts the sulphinic acid was obtained (65—70%).

(iii) Di-(*o*-phenylazophenyl) disulphoxide or its 2-nitro- or 4-nitro- or 2-benzylthio-derivative (0·5 g.) was treated with liquid ammonia (30—50 c.c.) below −50° for 5 hr., a test with ethanolic sodium hydroxide then showing complete conversion of the starting material. The mixture was worked up as under (ii), and the corresponding disulphide (85—90%) and sulphinic acid (75—85%) isolated.

The products obtained in all experiments were crystallised and identified as described earlier. At no stage was the blue colour of the sulphenate ion observed.

Di-(2-phenylazo-1-naphthyl) Disulphoxide and Sulphide.—Aqueous solutions of sodium 2-phenylazonaphthalene-1-sulphinate (0·3 g. in 20 c.c.) and of 2-phenylazonaphthalene-1-sulphenyl bromide (0·3 g. in 200 c.c.) were mixed, and the precipitate of the *disulphoxide* quickly filtered off, washed, and dried (0·4 g., 80%; m. p. 115—120°) (Found: C, 68·1; H, 4·3; N, 10·5. $C_{32}H_{22}O_2N_4S_2$ requires C, 69·1; H, 4·0; N, 10·0%). Attempts to purify the disulphoxide

yielded *di*-(2-*phenylazo*-1-*naphthyl*) *sulphide*, which crystallised from light petroleum (b. p. 80—100°) as reddish-brown needles, m. p. 198° (Found : C, 77·9; H, 4·4; N, 11·6. $C_{32}H_{22}N_4S$ requires C, 77·8; H, 4·4; N, 11·3%).

Action of Sodium Hydroxide (1 *Mol.*) *on* 2-*Phenylazonaphthalene*-1-*sulphenyl Bromide.*—Aqueous sodium hydroxide (0·01N; 146 c.c., ~1 mol.) was added at once to a well-stirred aqueous solution of the sulphenyl bromide (0·5 g. in 200 c.c.). After 30 min., the precipitate of the disulphide and the disulphoxide (and/or monosulphide), formed almost instantaneously, was filtered off (0·35 g.; m. p. 155—175°). The mixture was refluxed with ethanol (50 c.c.) for 1 hr. in order to ensure complete conversion of any disulphoxide into monosulphide, sodium sulphide nonahydrate (0·3 g.) and sodium hydroxide (0·25 g.) in water (15 c.c.) were added, and, after 3 min., the solution was cooled and diluted with water. The precipitated monosulphide was filtered off (0·08 g., 46%; m. p. and mixed m. p. 198°, from light petroleum). The mother-liquor containing the sodium mercaptide was acidified and extracted with benzene. The benzene layer was dried and concentrated to a small volume, and the precipitate of almost pure disulphide was collected (0·12 g., 65%; m. p. and mixed m. p. 205°, from benzene; Burawoy, Chaudhuri, and Hyslop[6] give 205°). The original mother-liquor did not contain any sulphinic acid.

Action of (*Wet*) *Liquid Ammonia on* 2-*Phenylazonaphthalene*-1-*sulphenyl Bromide.*—The sulphenyl bromide (0·5 g.) was added to well-stirred liquid ammonia (30 c.c.) below −50°. After 30 min., the ammonia was evaporated off, and the residue of the disulphide and the monosulphide washed with water. Treatment of a sample with cold aqueous sodium hydroxide did not yield any sulphinic acid. The mixture (0·32 g.; m. p. 155—190°) was separated by means of sodium sulphide as in the preceding experiment, yielding monosulphide (0·06 g., 35%; m. p. and mixed m. p. 198°, from light petroleum) and disulphide (0·12 g., 65%; m. p. and mixed m. p. 205°, from benzene). The same result was obtained when the reaction was allowed to proceed for 5 hr.

Action of Sodium Hydrogen Carbonate (1 *Mol.*) *on* 2-*Phenylazonaphthalene*-1-*sulphenyl Bromide.*—Sodium hydrogen carbonate (0·25 g., 1 mol.) in water (10 c.c.) was added at once to a well-stirred aqueous solution of the sulphenyl bromide (1·0 g. in 400 c.c.) which after 2 hr. started to become turbid. The reaction was allowed to proceed for 48 hr., and the precipitate of the disulphide, monosulphide, and 2-*phenylazonaphthalene*-1-*sulphenyl sulphite* filtered off. The sulphides (0·33 g., 43%) were removed by extraction with boiling benzene and separated and identified as in the preceding experiment. The benzene-insoluble sulphite (0·07 g., 8%) formed from ethanol reddish-brown solvated needles, m. p. 127—128° (Found : C, 62·7; H, 4·3; N, 8·9. $C_{32}H_{22}O_3N_4S_3.C_2H_6O$ requires C, 62·6; H, 4·3; N, 8·6%). The ethanol could not be removed below 100°. The original mother-liquor remained clear on storage, but contained an appreciable amount of unchanged 2-phenylnaphthothiadiazolium salt which, after 50 hr., was recovered, on addition of sodium perchlorate, as the sparingly soluble perchlorate (0·34 g., 32%; m. p. 214°; Burawoy, Chaudhuri, and Hyslop[6] give m. p. 216°).

2-*Phenylazonaphthalene*-1-*sulphenyl Sulphite.*—Sodium sulphite (0·08 g.) in water (10 c.c.) was added to 2-phenylazonaphthalene-1-sulphenyl bromide (0·4 g.) in water (200 c.c.). The precipitated sulphite (0·27 g., 76%) crystallised from ethanol as reddish-brown needles, m. p. 127—128°, not depressed by mixing with the product described in the preceding experiment. Crystallisation from methanol gave similar needles of *solvate*, m. p. 127—128° (Found : C, 62·0; H, 4·0; N, 9·0. $C_{32}H_{22}O_3N_4S_3.CH_4O$ requires C, 62·1; H, 4·1; N, 8·8%).

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132. *A New Method of Preparation of Aryl* iso*Thiocyanates.*

By J. N. Baxter, J. Cymerman-Craig, M. Moyle, and R. A. White.

Arylthioureas, when heated in chlorobenzene at 150° for 8—10 hr., undergo fission to give good yields of aryl *iso*thiocyanates containing 1, 2, 3, and 4 aromatic rings. The mechanism of the reaction has been investigated.

Methods of preparation of aryl *iso*thiocyanates [1] include (*a*) the use of thiocarbonyl chloride [2] or its precursor thiocarbonyl tetrachloride (the latter reaction fails with naphthyl compounds [3]), (*b*) acid-induced fission of an *NN'*-diarylthiourea, involving the loss of 1 mol. of amine, and (*c*) decomposition of an ammonium aryldithiocarbamate,[4] the last method giving low yields for naphthyl and other compounds.[5]

It has now been found [6] that arylthioureas, when heated in a suitable solvent at 150°, undergo fission into ammonia and the aryl *iso*thiocyanate. No *iso*thiocyanate was obtained on attempted vacuum-distillation of 4-diphenylyl- or α-naphthyl-thiourea without a solvent.

9-Phenanthryl- and 1-pyrenyl-thiourea were prepared by Frank and Smith's method; [7] the methods of de Clermont [8] and Bertram [9] failed for the latter substance. *N*-4-Diphenylylthiourea was obtainable by either method, or from *N*-4-diphenylylammonium thiocyanate. The related *N*-4-diphenylyl-*S*-methyl*iso*thiourea, ammonium *N*-4-diphenylyldithiocarbamate, and *N*-4-diphenylylguanidine were prepared, the last by heating *N*-4-diphenylyldiguanide.

When *N*-4-diphenylylthiourea was heated in solvents of various b. p.s, chlorobenzene gave optimum yields of *N*-4-diphenylyl *iso*thiocyanate; 1 : 2-dichlorobenzene also afforded the desired product, though in smaller yield, while nitrobenzene or 1 : 2 : 4-trichlorobenzene gave no *iso*thiocyanate. *N*-4-Diphenylyl *iso*thiocyanate had m. p. 63·5—64·5°, though Desai, Hunter, and Kureishy [10] claim m. p. 119—120°. Brewster and Horner [11] claim preparation of this *iso*thiocyanate by 3 hours' boiling of the *NN'*-diaryl thiourea with acetic anhydride. This procedure in our hands gave *NN*-diacetyl-4-aminodiphenyl, m. p. 118·5—119°, and *NN'*-diacetyl-*NN'*-bis-4-diphenylylurea, hydrolysed by alkali to 4-acetamidodiphenyl. Reaction of acetic anhydride with the *iso*thiocyanate afforded the same products. Werner [12] reported the action of acetic anhydride on *NN'*-diphenylthiourea to give phenyl *iso*thiocyanate in 96, 37, 7, and 0% yield after 5, 30, 45, and 60 minutes' boiling respectively, but did not identify the product of decomposition. This *iso*thiocyanate is known [13] to give the *N*-acylaniline and diphenylurea when treated with acetic or formic acid, while benzoic anhydride gives *NN*-dibenzoylaniline.[14] The mechanism of *iso*thiocyanate formation was investigated by using α-naphthylthiourea. The rate of evolution of ammonia at 150°, measured during 6 hr., gave the results shown in the Figure. A plot of $\log_{10} C_A^\circ/(C_A^\circ - C_{NH_3})$ (where C_A° = initial concentration of thiourea and C_{NH_3} = concentration of ammonia at time t) was linear only for 1·5 hr., although the " half-time " of the reaction (65 min.) was independent of the magnitude of C_A°. The possibility of the reaction's occurring in three successive steps (*a*), (*b*), and (*c*), with the intermediate formation of a dithiobiuret, could be dismissed in view of the failure of phenyl *iso*thiocyanate and phenylthiourea to give 1 : 5-diphenyldithiobiuret; only *NN'*-diphenylthiourea was obtained

[1] Review: Schroeder, *Chem. Rev.*, 1955, **55**, 181.
[2] Dyson and George, *J.*, 1924, 1702.
[3] Connolly and Dyson, *J.*, 1935, 679.
[4] Andreasch, *Monatsh.*, 1906, **27**, 1221; Kaluza, *ibid.*, 1912, **33**, 367.
[5] Dains, Brewster, and Olander, *Univ. Kansas Sci. Bull.*, 1922, **13**, 3.
[6] Baxter, Cymerman-Craig, Moyle, and White, *Chem. and Ind.*, 1954, 785.
[7] Frank and Smith, *Org. Synth.*, 1948, **28**, 89.
[8] De Clermont, *Ber.*, 1876, **9**, 446.
[9] Bertram, *Ber.*, 1892, **25**, 48.
[10] Desai, Hunter, and Kureishy, *J.*, 1936, 1668.
[11] Brewster and Horner, *Trans. Kansas Acad. Sci.*, 1937, **40**, 101.
[12] Werner, *J.*, 1891, 396.
[13] *Idem*, *J.*, 1891, 544; Cain and Cohen, *J.*, 1891, 327.
[14] Kay, *Ber.*, 1893, **26**, 2852.

when excess of *iso*thiocyanate was used; equimolar proportions of the reagents did not react even after 7 days at 100°. Curd, Davey, Richardson, and Ashworth [15] have reported abortive attempts to condense aryl *iso*thiocyanates with alkylthioureas, or alkyl *iso*thiocyanates with arylthioureas.

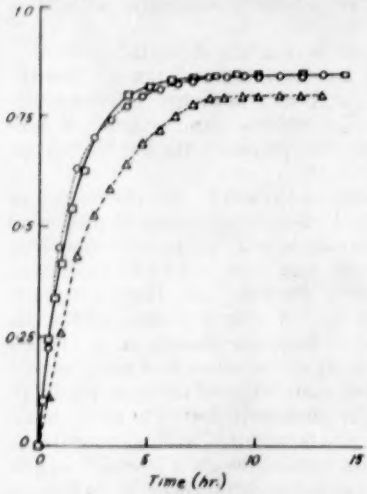
Moreover, 1 : 5-di-α-naphthyldithiobiuret, obtained by thiohydrolysis of 2-methyl-1 : 5-di-α-naphthyl-2-*iso*dithiobiuret which was prepared by Johnson's method,[16] did not evolve ammonia even after 6 hours' refluxing in chlorobenzene, and was recovered quantitatively.

(*a*) $R{\cdot}NH{\cdot}CS{\cdot}NH_2 \longrightarrow R{\cdot}NCS + NH_3$

(*b*) $R{\cdot}NCS + R{\cdot}NH{\cdot}CS{\cdot}NH_2 \longrightarrow R{\cdot}NH{\cdot}CS{\cdot}NH{\cdot}CS{\cdot}NH{\cdot}R$

(*c*) $R{\cdot}NH{\cdot}CS{\cdot}NH{\cdot}CS{\cdot}NH{\cdot}R \longrightarrow 2R{\cdot}NCS + NH_3$

Investigation of the reaction kinetics for periods up to 14 hr. showed that the evolution of ammonia had virtually ceased after 7 hr. when 85% of the theoretical amount of ammonia had been evolved (see Figure). Working-up after 8 hours' refluxing afforded



Rate of evolution of ammonia from α-naphthylthiourea in chlorobenzene at 150°

···○··· *Experimental values*, C_{NH_3}/C_A°.

—□— *Theor. curve*,

$$C_{NH_3}/C_A^\circ = \left(\frac{k_1 - k_2}{k_1 + k_2}\right)\{1 - \exp[-t(k_1 + k_2)]\}.$$

—△— *Experimental values*, $\ln [C_A^\circ/(C_A^\circ - C_{NH_3})]$.

the *iso*thiocyanate (86%) and (from a m. p.–composition diagram of the two pure components) a mixture of equal parts of α-naphthylthiourea and di-α-naphthylthiourea. These possess, like most pairs of arylthioureas and diarylthioureas, very similar m. p.s and solubilities, which render their separation difficult. A similar experiment, with working up after 14 hr., gave the *iso*thiocyanate (86%) and pure di-α-naphthylthiourea, while an experiment carried out for the " half-time " of the reaction (65 min.) gave the *iso*thiocyanate (41%), α-naphthylthiourea (53·5%), and a trace of di-α-naphthylthiourea (1·5%).

(*d*) $Ar{\cdot}NH{\cdot}CS{\cdot}NH_2 \xrightarrow[\text{Slow}]{k_1} Ar{\cdot}NCS + NH_3$

(*e*) $Ar{\cdot}NH{\cdot}CS{\cdot}NH_2 \xrightarrow[\text{Slow}]{k_2} Ar{\cdot}NH_3^+\ SCN^-$

(*f*) $Ar{\cdot}NH_3^+\ SCN^- + NH_3 \xrightarrow{\text{Fast}} Ar{\cdot}NH_2 + NH_4SCN$

(*g*) $Ar{\cdot}NH_2 + Ar{\cdot}NCS \xrightarrow{\text{Fast}} Ar{\cdot}NH{\cdot}CS{\cdot}NHAr$

As these materials together comprised 96% of the expected total, it was clear that no " intermediate compound " was involved. The increasing amounts of the *NN'*-diarylthiourea and the cessation of the evolution of ammonia could be explained by two

[15] Curd, Davey, Richardson, and Ashworth, *J.*, 1949, 1739.
[16] Johnson, *Amer. Chem. J.*, 1903, **30**, 167.

simultaneous first-order reactions (*d*) and (*e*), followed by the known fast reactions (*f*) and (*g*), which would result in the removal of some of the products of reaction (*d*) to form the *NN'*-diarylthiourea. Assuming reactions (*d*) and (*e*) to be rate-determining, and (*f*) and (*g*) to be very fast compared with (*d*) and (*e*), then the following conditions hold :

$$dC_{NH_3}/dt = (k_1 - k_2)C_A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$-dC_A/dt = (k_1 + k_2)C_A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$C_A = C_A^\circ \exp[-t(k_1 + k_2)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

whence

$$dC_{NH_3}/dt = (k_1 - k_2)C_A^\circ \exp[-t(k_1 + k_2)] \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and

$$\frac{C_{NH_3}}{C_A^\circ} = \left(\frac{k_1 - k_2}{k_1 + k_2}\right)\{1 - \exp[-t(k_1 + k_2)]\} \quad . \quad . \quad . \quad (5)$$

When $t = \infty$, from (5) we get :

$$C_{NH_3}/C_A^\circ = (k_1 - k_2)/(k_1 + k_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5a)$$

Further, (5) can be re-written in the form

$$\ln \frac{C_A^\circ - C_{NH_3}}{C_A^\circ} = \ln\left[1 - \left(\frac{k_1 - k_2}{k_1 + k_2}\right)\{1 - \exp[-t(k_1 + k_2)]\}\right] \quad . \quad (6)$$

Expanding the exponential and the logarithmic term, and neglecting terms in t^3 and higher powers of t, we have :

$$\ln[(C_A^\circ - C_{NH_3})/C_A^\circ] = -t(k_1 - k_2)(1 - k_2t)$$

so that

$$2{\cdot}303 \log_{10}[C_A^\circ/(C_A^\circ - C_{NH_3})] = t(k_1 - k_2)(1 - k_2t) \quad . \quad . \quad . \quad . \quad (7)$$

When t is very small ($t \ll 1$), then since k_2 is very small (see below), $(1 - k_2t) = ca.\ 1$ and

$$2{\cdot}303 \log_{10}[C_A^\circ/(C_A^\circ - C_{NH_3})] = ca.\ t(k_1 - k_2) \quad . \quad . \quad . \quad . \quad . \quad (7a)$$

From the Figure, at $t = \infty$, equation (5*a*) gives

$$C_{NH_3}/C_A^\circ = 0{\cdot}845 = (k_1 - k_2)/(k_1 + k_2). \quad . \quad . \quad . \quad (8)$$

so that $k_1 = 11{\cdot}90k_2$.

The initial slope of the logarithmic curve in the Figure is constant up to $t = 1$, and, from (7*a*), slope $= 0{\cdot}25 = (k_1 - k_2)/2{\cdot}303$, so that

$$k_1 = 0{\cdot}576 + k_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

From (8) and (9), $k_1 = 0{\cdot}629$ hr.$^{-1}$ and $k_2 = 0{\cdot}053$ hr.$^{-1}$. A plot of the theoretical curve (5), with these values of k_1 and k_2 (Figure) is in excellent agreement with the experimental values. Further, a plot of $[C_{NH_3}/C_A^\circ]_{obs.}$ against $\exp[-t(k_1 + k_2)]$ is linear.

Measurement of the reaction rate in the highly polar benzonitrile gave a greatly reduced rate, only 45% of the theoretical amount of ammonia being evolved after 6·5 hr. From the initial slope of the logarithmic curve for this solvent (0·07), it follows that $k_1' = 0{\cdot}161 + k_2'$ in this case. No α-naphthyl *iso*thiocyanate could be isolated after 6·5 hr. in this solvent; it is possible that the more polar medium preferentially enhances the reaction (*e*) involving the more polar species. In the less polar chlorobenzene, free ions are less likely to exist, though transitory formation of ion-pairs may occur. The fact that reaction in the non-polar xylene gave 86·5% of the *iso*thiocyanate after 8 hr. is in agreement with this suggestion.

Application of the synthetic method to other arylthioureas showed that 8—10 hours' heating in chlorobenzene at 150° gave good yields of aryl *iso*thiocyanates for systems containing 1, 2, 3, and 4 aromatic rings.

The action of heat on α-naphthylurea in the same solvent gave no α-naphthyl *iso*cyanate, although ammonia was evolved. The residue was a mixture of 1 : 5-di-α-naphthylbiuret (8%) and *NN'*-di-α-naphthylurea (86%). Probably reactions (*h*)—(*k*) [17] and (*l*) [18] occur :

(*h*) $R{\cdot}NH{\cdot}CO{\cdot}NH_2 \longrightarrow R{\cdot}NCO + NH_3$
(*i*) $R{\cdot}NH{\cdot}CO{\cdot}NH_2 \longrightarrow R{\cdot}NH_3{}^+OCN^-$
(*j*) $R{\cdot}NH_3{}^+OCN^- + NH_3 \longrightarrow R{\cdot}NH_2 + NH_4{}^+OCN^-$
(*k*) $R{\cdot}NH_2 + R{\cdot}NCO \longrightarrow CO(NHR)_2$
(*l*) $R{\cdot}NH{\cdot}CO{\cdot}NH_2 + R{\cdot}NCO \longrightarrow NH(CO{\cdot}NHR)_2$

The theoretical increase in the rate of reactions of the more polar CO compounds, compared with their less reactive CS analogues, is shown not only in the increased rates of reactions (*i*)—(*k*), but also in the occurrence of reaction (*l*), which does not take place at all in the CS series. As expected, reactions (*i*)—(*k*) are much faster than (*l*).

Experimental

Kinetic Measurements.—α-Naphthylthiourea (2·02 g., 0·01 mole) was placed in a small 3-necked flask through which was passed a slow stream of dry nitrogen, saturated with chlorobenzene vapour. The gas passed out through a double-surface condenser into a known volume of 0·1N-hydrochloric acid. The temperature was kept at 150° by the use of an oil-bath, and at zero time heated chlorobenzene (40 c.c.) was added to the thiourea. The rate of evolution of ammonia was measured by back-titration of 1 c.c. samples of the acid with 0·02N-barium hydroxide.

Determination of "Half-time."—When 2·02 g. of α-naphthylthiourea were dissolved in 40 c.c. (0·25M-solution), 45 c.c. (0·222M-solution), or 60 c.c. (0·167M-solution) of chlorobenzene, 50% of the theoretical volume of ammonia was evolved after 65 min. in each case.

Preparation of Aryl iso*Thiocyanates.*—M. p.s of thioureas were determined at the same time as a mixed m. p. and that of the pure thiourea as standard. Mixtures of thioureas and dithioureas were fractionally crystallised, and where inseparable, were analysed by m. p.–composition diagrams and mixed m. p.s with pure substances and with standard mixtures.

α-*Naphthyl* iso*thiocyanate.* (*a*) α-Naphthylthiourea (16·16 g.) and chlorobenzene (180 c.c.) were heated under reflux at 150° for 8 hr., and the chlorobenzene distilled off *in vacuo* first at 20 mm. and then at 1 mm. The residue was extracted with hexane (4 × 30 c.c.), and removal of solvent from the combined extracts gave α-naphthyl *iso*thiocyanate (12·75 g., 86%) as needles, m. p. 58—58·5° (lit., 58°). The hexane-insoluble solid (1·3 g.) consisted of α-naphthylthiourea (0·65 g., 4%) and di-α-naphthylthiourea (0·65 g., 5%).

(*b*) Repetition of the above experiment but with refluxing for 14 hr. gave α-naphthyl *iso*thiocyanate (86%) and di-α-naphthylthiourea (1·4 g., 10·5%). No α-naphthylthiourea remained.

(*c*) Refluxing of α-naphthylthiourea (4·04 g.) and chlorobenzene (40 c.c.) at 150° for 65 min. gave, on cooling to 0°, unchanged α-naphthylthiourea (1·85 g., 46%). Removal of solvent from the combined filtrate and hexane washings, and extraction of the residue with hexane, gave α-naphthyl *iso*thiocyanate (1·5 g., 41%) as the hexane-soluble, and a mixture of α-naphthylthiourea (0·3 g., 7·5%) and di-α-naphthylthiourea (0·05 g., 1·5%) as the hexane-insoluble portion.

(*d*) α-Naphthylthiourea (6·73 g.) and xylene (100 c.c.) were refluxed at 150° for 8 hr., the solvent was removed *in vacuo*, and the residue extracted with hexane. The hexane-soluble portion was α-naphthyl *iso*thiocyanate (5·33 g., 86·5%), and the hexane-insoluble fraction weighed 0·1 g.

Phenyl iso*thiocyanate.* Phenylthiourea (6·1 g.) and chlorobenzene (60 c.c.) were refluxed at 150° for 8 hr. On cooling to 0°, recovered phenylthiourea separated (1·5 g., 24·5%). Evaporation of the filtrate and hexane washings, extraction of the residue with hexane, and distillation of the extracts gave phenyl *iso*thiocyanate (2·37 g., 44%), b. p. 110—112°/20 mm., $n_D^{23\cdot5}$ 1·6465 (lit., b. p. 95°/12 mm., $n_D^{23\cdot5}$ 1·6490). The hexane-insoluble fraction was diphenylthiourea (1·2 g., 26%).

o-*Chlorophenyl* iso*thiocyanate.* Refluxing *o*-chlorophenylthiourea (18·65 g.) in chlorobenzene (140 c.c.) at 150° for 8 hr. and working up as described for the phenyl analogue gave unchanged

[17] Cf. Davis and Underwood, *J. Amer. Chem. Soc.*, 1922, **44**, 2595.
[18] Kuhn and Hentschel, *Ber.*, 1888, **21**, 504.

o-chlorophenylthiourea (3·25 g., 17·5%), and *o*-chlorophenyl *iso*thiocyanate (7·9 g., 46·5%), b. p. 91°/1·5 mm., $n_D^{22·5}$ 1·6604 (Found: C, 49·6; H, 2·35. Calc. for C_7H_4NClS: C, 49·6; H, 2·3%). Dyson *et al.*[19] give b. p. 260—262°/760 mm. The *iso*thiocyanate, with *o*-chloroaniline at 100° formed di-*o*-chlorophenylthiourea, m. p. 132—133°. The hexane-insoluble portion was di-*o*-chlorophenylthiourea (3·2 g., 23·5%).

N-4-*Diphenylylthiourea.*—(*a*) Preparation by a modification of Frank and Smith's method [7] gave *N*-4-diphenylylthiourea (92·5%) as plates, m. p. 190·5—191° (from propan-2-ol) (Found: N, 12·15. Calc. for $C_{13}H_{12}N_2S$: N, 12·25%).

(*b*) A mixture of 4-diphenylylammonium chloride and ammonium thiocyanate (5 mols.) in water, after refluxing for 4 hr., gave, on cooling, *N*-4-diphenylylthiourea (84·5%), m. p. 190°. With rapid heating, this resolidified and then had m. p. 219° (decomp.) (Found: C, 68·6; H, 5·6; N, 12·05; S, 13·6. Calc. for $C_{13}H_{12}N_2S$: C, 68·4; H, 5·3; N, 12·25; S, 14·0%). Desai *et al.*[20] give m. p. 204°.

4-Diphenylylammonium Thiocyanate.—A solution of 4-aminodiphenyl (3·38 g.) in ether (100 c.c.), treated with ethereal thiocyanic acid (from 1·67 g. of ammonium thiocyanate [20]), gave the *thiocyanate* (3·8 g., 83%), crystallising from ethyl acetate (with the minimum of heating) as prisms, m. p. 155—156° (bath pre-heated to 155°) (Found: C, 68·7; H, 5·4. $C_{13}H_{11}N,HSCN$ requires C, 68·4; H, 5·3%). It gave a thiocyanate test with ferric chloride and was converted into the thiourea by boiling water in presence of a trace of acid or alkali.

N-4-*Diphenylyl*-S-*methylisothiourea.*—*N*-4-Diphenylylthiourea (2·28 g.), methyl iodide (1·5 g.), and ethanol (20 c.c.), refluxed for 20 min., gave, on cooling, N-4-*diphenylyl*-S-*methylthiuronium iodide* (3·3 g., 89%) as prisms, m. p. 203—205°, unchanged on crystallisation from alcohol–ether (Found: N, 7·65. $C_{14}H_{14}N_2S,HI$ requires N, 7·6%). The *base*, obtained by using dilute ammonia solution, formed needles, m. p. 161—161·5° (decomp.; bath pre-heated to 150°) (Found: N, 11·75. $C_{14}H_{14}N_2S$ requires N, 11·6%).

Ammonium 4-Diphenylyldithiocarbamate.—Ammonia solution (15 c.c.; *d* 0·880) was added to 4-aminodiphenyl (17 g.) and carbon disulphide (10 c.c.) in alcohol (30 c.c.) with shaking; the mixture was kept at 10° for 3 hr. The solid was washed with ether and recrystallised by refluxing with methanol (100 c.c. per g.) for 1 min., filtering hot, and chilling the filtrate to 0°, giving the *ammonium salt* (7·8 g., 30%) as pale yellow plates, m. p. 105—106° (decomp.) (Found: N, 10·2. $C_{13}H_{14}N_2S_2$ requires N, 10·6%). Further recrystallisation or heating gave *NN'*-bis-4-diphenylylthiourea, m. p. and mixed m. p. 228°.

N-4-*Diphenylyldiguanide.*—Prepared by refluxing a mixture of 4-diphenylylammonium chloride (9·86 g.), dicyandiamide (4·4 g., 1·1 mol.), and alcohol (100 c.c.) for 7·5 hr., N-4-*diphenylyldiguanide hydrochloride* (9·3 g., 67%) crystallised from aqueous alcohol as prisms, m. p. 236·5—237° (Found: N, 24·1. $C_{14}H_{15}N_5,HCl$ requires N, 24·15%). The benzenesulphonate (m. p. 214—215°) was identical with that reported by Baxter *et al.*[21]

N-4-*Diphenylylguanidine.*—*N*-4-Diphenylyldiguanide benzenesulphonate (3·9 g.) was heated at 200—210° for 1 hr. Crystallisation from water gave *N*-4-diphenylylguanidinium benzenesulphonate (1·09 g., 31%), m. p. and mixed m. p. 170—171°.

4-Diphenylyl iso*Thiocyanate.*—Reaction of *N*-4-diphenylylthiourea (4·56 g.) in chlorobenzene (60 c.c.) at 150° for 6 hr. gave 4-diphenylyl *iso*thiocyanate (2·08 g., 49%), crystallising from light petroleum (b. p. 40—60°) as pale yellow needles, m. p. 63·5—64·5°, b. p. 340°/760 mm. (Found: C, 73·85; H, 4·4. Calc. for $C_{13}H_9NS$: C, 73·9; H, 4·2%). Brewster and Horner [11] report m. p. 60°, but Desai *et al.*[20] give m. p. 119—120°. The *iso*thiocyanate reacted quantitatively with 4-aminodiphenyl in benzene, to give bis-4-diphenylylthiourea, m. p. and mixed m. p. 228—229°.

The hexane-insoluble portion (3·1 g.) consisted of *N*-4-diphenylylthiourea (0·33 g., 7%) and bis-4-diphenylylthiourea (1·5 g., 39·5%).

Action of Acetic Anhydride on NN'-Bis-4-diphenylylthiourea.—Acetic anhydride (30 c.c.) and bis-4-diphenylylthiourea (7·6 g.) were refluxed for 3 hr., the solvent was removed *in vacuo*, and the residue extracted (Soxhlet) with light petroleum (b. p. 40—60°). Evaporation of the light petroleum extract gave *NN*-diacetyl-4-aminodiphenyl (4·1 g., 82%), crystallising from light petroleum as needles, m. p. 118·5—119° (Found: C, 75·45; H, 5·8. Calc. for $C_{16}H_{15}O_2N$: C, 75·85; H, 5·9%). Scarborough and Waters [22] give m. p. 121° (corr.).

Reaction of *NN*-diacetyl-4-aminodiphenyl with 4-aminodiphenyl (1 mol.) in boiling benzene

[19] Dyson, George, and Hunter, *J.*, 1926, 3042.
[20] Kaufmann and Kogler, *Ber.*, 1925, **58**, 1554.
[21] Baxter, Cymerman, and Sheldon, *J.*, 1951, 2342.
[22] Scarborough and Waters, *J.*, 1927, 1139.

gave 4-acetamidodiphenyl (100%), m. p. and mixed m. p. 169°. Hydrolysis of *NN*-diacetyl-4-aminodiphenyl with 2·5N-sodium hydroxide or 2N-sulphuric acid gave 4-acetamidodiphenyl (80%), m. p. and mixed m. p. 169°.

The petroleum-insoluble residue from the Soxhlet extraction crystallised from alcohol as plates (4·15 g., 46%) of NN'-*diacetyl*-NN'-*bis*-4-*diphenylylurea*, m. p. 148·5—149° (Found: C, 77·95; H, 5·8; N, 6·2; O, 10·8%; *M* (Rast), 435. $C_{29}H_{24}O_3N_2$ requires C, 77·7; H, 5·4; N, 6·25; O, 10·7%; *M*, 448). Refluxing the urea with 2·5N-sodium hydroxide gave 4-acetamidodiphenyl, m. p. and mixed m. p. 169°.

Action of Acetic Anhydride on 4-*Diphenylyl* iso*Thiocyanate.*—Acetic anhydride (7 c.c.) and 4-diphenylyl *iso*thiocyanate (1·06 g.) were refluxed for 3 hr. Working-up as above gave *NN*-diacetyl-4-aminodiphenyl (0·83 g., 66%), m. p. and mixed m. p. 118—119°, and *NN'*-diacetyl-*NN'*-bis-4-diphenylylurea (0·3 g., 27%), m. p. and mixed m. p. 147·5—148°.

β-*Naphthyl* iso*Thiocyanate.*—Obtained by refluxing β-naphthylthiourea (16·2 g.) in chlorobenzene (180 c.c.) for 10 hr. at 150°, β-naphthyl *iso*thiocyanate (10·4 g., 70%) formed yellowish needles, m. p. 61—62° (lit., m. p. 62—63°). The hexane-insoluble portion consisted of β-naphthylthiourea (1·08 g., 6·5%) and di-β-naphthylthiourea (1·75 g., 13·5%).

p-*Bromophenyl* iso*Thiocyanate.*—Reaction of *p*-bromophenylthiourea (18·5 g.) in chlorobenzene (200 c.c.) at 150° for 8 hr. gave the *iso*thiocyanate (12·5 g., 73%) as yellow needles, m. p. 60—61° (lit., m. p. 61°). The hexane-insoluble solid was a mixture of *p*-bromophenylthiourea (1·1 g., 6%) and di-*p*-bromophenylthiourea (1·1 g., 7%).

9-*Phenanthrylthiourea.*—Prepared by an adaptation of Frank and Smith's method,[7] 9-phenanthrylthiourea (64%) crystallised from propan-2-ol as plates, m. p. 203—204° (decomp.). May [23] gives m.p. 203—204° (decomp.).

9-*Phenanthryl* iso*Thiocyanate.*—Reaction of 9-phenanthrylthiourea (4·65 g.) in chlorobenzene (70 c.c.) at 150° for 10 hr., followed by removal of solvent *in vacuo* and Soxhlet-extraction of the residue with light petroleum (b. p. 60—90°), gave 9-phenanthryl *iso*thiocyanate (3·15 g., 73%) as yellow needles, m. p. 102·5—103° (Found: C, 76·3; H, 4·0; N, 5·8. Calc. for $C_{15}H_9NS$: C, 76·55; H, 3·85; N, 5·95%). May [23] gives m. p. 103—103·5°. The petroleum-insoluble portion contained 9-phenanthrylthiourea (0·2 g., 4%) and bis-9-phenanthrylthiourea (0·4 g., 10%).

1-*Pyrenylthiourea.*—Prepared by an adaptation of Frank and Smith's method [7] from 1-aminopyrene, 1-*pyrenylthiourea* (5·5 g., 80%) crystallised from chlorobenzene as yellow prisms, m. p. 207—207·5° (Found: C, 73·65; H, 4·4. $C_{17}H_{12}N_2S$ requires C, 73·9; H, 4·4%).

1-*Pyrenyl* iso*Thiocyanate.*—Refluxing 1-pyrenylthiourea (4·1 g.) in chlorobenzene (60 c.c.) for 10 hr. at 150°, followed by removal of solvent and Soxhlet extraction with *n*-hexane, gave 1-*pyrenyl* iso*thiocyanate* (2·75 g., 73%), crystallising from chloroform as orange prisms, m. p. 125—125·5° (Found: C, 78·4; H, 3·5. $C_{17}H_9NS$ requires C, 78·7; H, 3·5%). The *iso*thiocyanate reacted with 1-aminopyrene in benzene, to give bis-1-pyrenylthiourea, m. p. 217—219° (lit., m. p. 218—219°). The hexane-insoluble portion contained 1-pyrenylthiourea (0·5 g., 12%) and bis-1-pyrenylthiourea (0·5 g., 14%).

Attempted Preparation of 1 : 5-*Diphenyldithiobiuret.*—Phenylthiourea (3·12 g., 1 mol.) and phenyl *iso*thiocyanate (10 g., 4 mols.) were heated at 150° for 0·5 hr. The cold mass was extracted with benzene, the extract affording diphenylthiourea (2 g., 44%) as plates (from alcohol), m. p. and mixed m. p. 149—150°. No phenylthiourea or diphenyldithiobiuret was isolated.

Action of Alkali on S-*Methyl*-N-*phenylthiuronium Iodide.*—(*a*) Addition of dilute aqueous ammonia to a solution of *S*-methyl-*N*-phenylthiuronium iodide at 0° gave *S*-methyl-*NN'*-diphenyl*iso*thiourea as needles (from alcohol), m. p. 109° (Found: C, 69·35; H, 5·85; N, 11·05. Calc. for $C_{14}H_{14}N_2S$: C, 69·4; H, 5·85; N, 11·5%). Délepine [24] gives m. p. 109°. (*b*) The action of sodium carbonate on the hydriodide at 0° gave the desired *S*-methyl-*N*-phenyl-*iso*thiourea (96%).

S-*Methyl*-N-α-*naphthyliso*thiourea.—Refluxing α-naphthylthiourea (30·3 g.) and methyl iodide (21·5 g.) in alcohol (750 c.c.) for 20 min. gave, on removal of solvent, S-*methyl*-N-α-*naphthylthiuronium iodide* as prisms, m. p. 182—183° (Found: C, 42·2; H, 3·9. $C_{12}H_{12}N_2S,HI$ requires C, 41·9; H, 3·8%). Treatment of this salt with sodium carbonate at 0° gave the *isothiourea* (75%), crystallising from chloroform–light petroleum (b. p. 60—90°) as prisms, m. p. 88—89° (Found: C, 66·55; H, 5·5. $C_{12}H_{12}N_2S$ requires C, 66·65; H, 5·5%).

[23] May, *J. Org. Chem.*, 1947, **12**, 443.
[24] Délepine, *Bull. Soc. chim. France*, 1902, **27**, 807.

2-Methyl-1 : 5-di-α-naphthyl-2-isodithiobiuret.—Reaction of the above *iso*thiourea (20 g.) and α-naphthyl *iso*thiocyanate in dry ether (800 c.c.) at room temperature for 12 hr. gave the *isodithiobiuret* (25 g., 65%), crystallising from chloroform–light petroleum as prisms, m. p. 138—138·5° (Found : C, 68·5; H, 4·75. $C_{23}H_{19}N_3S_2$ requires C, 68·8; H, 4·75%).

1 : 5-Bis-α-naphthyldithiobiuret.—A boiling solution of the preceding *iso*dithiobiuret (10 g.) and sodium sulphide (10 g.) in alcohol (400 c.c.) and water (20 c.c.) was treated with hydrogen sulphide for 1 hr. Removal of solvent, acidification (acetic acid), and extraction (Soxhlet) of the solid with chloroform gave the *dithiobiuret* (5·2 g., 54%), as needles (from chloroform), m. p. 220—221° (Found : C, 67·9; H, 3·95. $C_{23}H_{17}N_3S_2$ requires C, 68·15; H, 4·4%).

Attempted Preparation of α-Naphthyl isoCyanate.—α-Naphthylurea (4·6 g.) and chlorobenzene (40 c.c.) were refluxed for 8 hr. Evolution of ammonia set in at once, but dissolution did not take place. On cooling, the solid was filtered off (3·7 g.) and fractionally crystallised from acetic acid. The most soluble fraction was 1 : 5-di-α-naphthylbiuret (0·34 g., 8%), m. p. 276—278° (lit., m. p. 278—279°). A mixed m. p. with di-α-naphthylurea was depressed by 30°. The remainder was di-α-naphthylurea (86%), m. p. 285—290° (decomp.) [lit., m. p. 284—287° (decomp.)]. The original chlorobenzene filtrate left no residue on evaporation.

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133. *Organic Peroxides. Part VI.* A Stereochemical Investigation of the Preparation and Reactions of 1-Phenylethyl Hydroperoxide.*

By ALWYN G. DAVIES and R. FELD.

The acid-catalysed oxidation of optically active 1-phenylethanol (I) to 1-phenylethyl hydroperoxide (II) with 90% hydrogen peroxide gives a value of α_{II}/α_I (α = optical rotation) varying between −0·069 and −0·146 in different preparations. In the reduction of the hydroperoxide back to the alcohol (III) directly or through its triphenylmethyl derivative, with a wide variety of reagents, α_{III}/α_{II} is constant (+0·28 to +0·33) within the experimental error, but α_{III}/α_I varies between −0·019 and −0·036, because of variation in α_{II}/α_I. It is concluded that the reductions all involve 100% retention of configuration and therefore the oxidation of 1-phenylethanol proceeds with inversion accompanied by a high degree of racemisation. This supports our conclusion that the alcohol is oxidised principally by an S_N1-like mechanism.

WE have previously presented evidence (summarised in Part V [1]) that the acid-catalysed oxidation of alcohols with hydrogen peroxide or alkyl hydroperoxides proceeds by alkyl–oxygen heterolysis of the alcohol, usually by an S_N1 mechanism. With optically active alcohols, which do not carry groups which assist retention of configuration, this mechanism usually involves racemisation accompanied by varying amounts of stereochemical inversion,[2] and we have shown that active 1 : 2 : 3 : 4-tetrahydro-1-naphthol yields the inactive hydroperoxide. As the reactivity of alcohols by this mechanism, and the degree of racemisation in the intermediate carbonium ion, are both dependent on the stability of the ion, it follows that the less reactive alcohols might retain some optical asymmetry. We have accordingly investigated the stereochemical course of the reaction of a number of optically active alcohols (and their esters and ethers) with hydrogen peroxide; the results for active 1-phenylethanol are now reported.

The problem of relating the configuration of reactant and product would be simple if the hydroperoxide could be reduced back to the alcohol by a reaction which was known unambiguously to involve simple O–O fission and therefore retention of configuration of the alkyl group. No compelling evidence, however, is available of the mechanism of any of the possible reductions. Williams and Mosher [3] assumed that catalytic hydrogenation

* Part V, *J.*, 1955, 2471. A preliminary note of the present work has appeared in *Chem. and Ind.*, 1954, 1322.

[1] Bassey, Bunton, Davies, Lewis, and Llewellyn, *J.*, 1955, 2471.
[2] Ingold, "Structure and Mechanism in Organic Chemistry," Bell, London, 1953, p. 386.
[3] Williams and Mosher, *J. Amer. Chem. Soc.*, 1954, **76**, 3495.

over palladium and the reaction with lithium aluminium hydride [4] followed this simple course, although both reactions in principle might involve some racemisation.[5] Kornblum and de la Mare [6] showed that the pyrolysis of *tert.*-butyl 1-phenylethyl peroxide in the presence of thiophenol as a hydrogen donor gave, *via* the alkoxy-radical, the alcohol with little or no racemisation in the 1-phenylethyl group; similarly, if the hydrogen sulphite reduction of a hydroperoxide proceeds through the alkoxy-radical as Kharasch and his co-workers suggest,[7] the alkyl group might be expected to retain its asymmetry, although this result might be dependent upon pH.[8] In the present work, the problem has been overcome by correlating the optical results of reduction, a large variety of reagents being used.

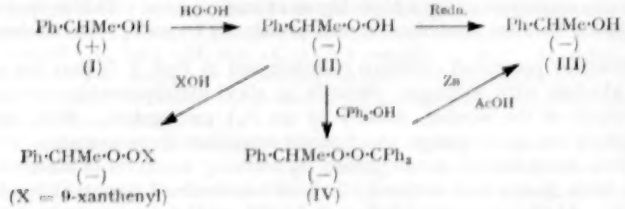
Optically active (+)1-phenylethanol (I) reacted with 90% hydrogen peroxide in the presence of sulphuric acid to yield active (−)1-phenylethyl hydroperoxide (II) with a value of α_{II}/α_I varying between −0·069 and −0·146 (see Table 2), the negative sign indicating inversion of sign of rotation; the product was shown to racemise only slowly under the reaction conditions. The active hydroperoxide was then reduced to the (−) alcohol (III) with a wide variety of reagents, giving a positive value of α_{III}/α_{II} which was constant within the experimental error (Table 1), but with values of α_{III}/α_I varying between −0·019 and −0·036, because of variation in α_{II}/α_I.

TABLE 1. *Reduction of active* 1-*phenylethyl hydroperoxide* (II) *and* 1-*phenylethyl triphenylmethyl peroxide* (IV).

Peroxide ...	(II)						(IV)
Reagent ...	Na_2SO_3	$LiAlH_4$	Zn–HOAc	$SnCl_2$	$C_7H_7{\cdot}SO_2Na$	H_2–Pt	Zn–HOAc
α_{III}/α_{II}	+0·29, +0·31	+0·25 [a]	+0·28	+0·32	+0·33	+0·28	+0·28

[a] This low value is probably caused by a fraction of the reduction proceeding *via* acetophenone—see later.

When the hydroperoxide (II) obtained from the optically pure alcohol (I) was alkylated with triphenylmethanol or xanthhydrol, it gave the corresponding partially racemised derivatives whose optical purity could be increased by fractional crystallisation. Active 1-phenylethyl triphenylmethyl peroxide (IV), which had not been fractionated, was reduced to 1-phenylethanol (III) with zinc and acetic acid; α_{III}/α_{II} is recorded in Table 1.



The Reduction of the Peroxides.—It would be most surprising if the wide variety of reagents used in the eight methods of reduction all gave the same degree of racemisation during reaction. Similarly, it is difficult to envisage all these reductions proceeding with 100% inversion of configuration. The value of α_{III}/α_{II}, which is constant within the experimental error, must therefore imply that all these reactions proceed with essentially 100% retention of configuration in the 1-phenylethyl group. Powerful support for this is afforded by the demonstration [9] that the reduction of 1-phenylethyl hydroperoxide with sodium [^{18}O]sulphite in [^{18}O]water yields the isotopically normal alcohol; it thus appears that the alkyl–oxygen bond remains intact during the reduction. Similarly the fact that

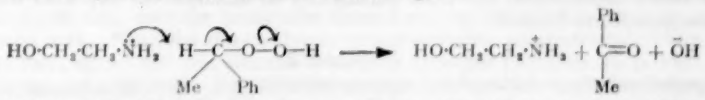
[4] Cf. Russell, *J. Amer. Chem. Soc.*, 1953, **75**, 5011.
[5] (*a*) Davies and Elton, *J.*, 1952, 3298; (*b*) Kornblum and de la Mare, *J. Amer. Chem. Soc.*, 1951, **73**, 851.
[6] *Idem, ibid.*, 1952, **74**, 3079.
[7] Kharasch and co-workers, *J. Org. Chem.*, 1951, **16**, 113; *J. Amer. Chem. Soc.*, 1939, **61**, 3092.
[8] Halperin and Taube, *ibid.*, 1952, **74**, 380.
[9] M. Bassey, unpublished work.

no trace of 1-phenylethyl *p*-tolyl sulphone could be isolated from the reduction of the hydroperoxide with sodium toluene-*p*-sulphinate implies that the reaction does not proceed by unimolecular alkyl–oxygen heterolysis.

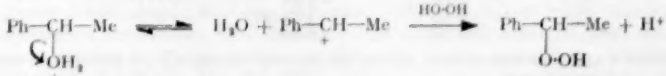
We assume therefore that all these reductions proceed with 100% retention of configuration. It follows that 1-phenylethanol and 1-phenylethyl hydroperoxide of the same sign of rotation have corresponding configurations (cf. heptan-2-ol and 1-methylhexyl hydroperoxide [3]), and the maximum rotation of 1-phenylethanol being assumed to be $\alpha_D = 44{\cdot}2°$ (*l*, 1·0),[10] 1-phenylethyl hydroperoxide has a maximum rotation of α_D = about 140° (*l*, 1·0).

Kharasch and his co-workers' suggestion [7] that the reduction of 1-methyl-1-phenylethyl hydroperoxide with sodium hydrogen sulphite proceeds by a mechanism involving the $PhMe_2CO\cdot$ radical, was based on the observation that the addition of styrene to the reaction mixture permits isolation of 2-phenylethanesulphonic acid and 2-hydroxy-2-phenylethanesulphonic acid. Halperin and Taube,[8] however, have shown that in the acid reduction of [$^{18}O_2$]hydrogen peroxide with sulphite, *both* labelled oxygen atoms are located in the sulphate which is formed. They suggest that this reaction is heterolytic and proceeds by the formation and subsequent intramolecular rearrangement of peroxysulphurous acid, $H^{18}O\cdot{}^{18}O\cdot SO\cdot OH$. If a similar mechanism applied to the sulphite reduction of 1-phenylethyl hydroperoxide it would involve alkyl–oxygen fission in the peroxy-ester, $CHMePh\cdot{}^{18}O\cdot{}^{18}O\cdot SO\cdot OH$, with a stereochemical result probably differing from 100% retention. We attempted to reduce the hydroperoxide under acid conditions, but at pH 0 and 1 obtained only acetophenone; at pH 5 a mixture of acetophenone and 1-phenylethanol was obtained.

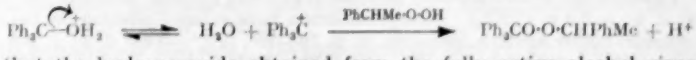
Acetophenone was also isolated from the attempted reduction of 1-phenylethyl hydroperoxide with 2-aminoethanol [11] and of 1-phenylethyl triphenylmethyl peroxide with sodium and ethanol or methanol. This presumably arises by base-catalysed O–O heterolysis of the type described by Kornblum and de la Mare,[5b] *e.g.*:



The Oxidation of the Alcohol.—If it is accepted then that the hydroperoxide is reduced with 100% retention of configuration, the low, negative, and variable values of α_{III}/α_I, which appear in the final column of Table 2, express the percentage of retention of configurational purity occurring during the oxidation of 1-phenylethanol which proceeds with inversion accompanied by a high degree of racemisation.* This is compatible with our suggestion that the reaction proceeds through the intermediate formation of the 1-phenylethylium ion:



The oxidation of triphenylmethanol with 1-phenylethyl hydroperoxide involves no loss of asymmetry in the 1-phenylethyl group, as the value of α_{III}/α_{II}, obtained in reductions of 1-phenylethyl triphenylmethyl peroxide, is not depressed. This again is compatible with the S_N1 mechanism for the reaction which we have proposed:



The fact that the hydroperoxide obtained from the fully active alcohol gives optically impure triphenylmethyl and 9-xanthenyl derivatives, also therefore establishes that the initial oxidation of 1-phenylethanol involves some racemisation.

* The active hydroperoxide can be converted into its sodium salt and recovered without loss of optical purity; we therefore do not consider that any optical asymmetry arises because of restriction of rotation about the O–O bond in the skew structure of the peroxide.[12]

[10] Downer and Kenyon, *J.*, 1939, 1156.
[11] Cf. Capp and Hawkins, *J.*, 1953, 4106.
[12] Davies, *Discuss. Faraday Soc.*, 1953, **14**, 140.

Two other reports of work on the stereochemistry of the preparation of peroxides have appeared. Kornblum and de la Mare [6] obtained optically active *tert.*-butyl 1-phenylethyl peroxide by the interaction of potassium *tert.*-butyl peroxide and active 1-phenylethyl bromide, and Williams and Mosher [3] prepared active 1-methylhexyl hydroperoxide by the alkaline perhydrolysis of active 1-methylhexyl methanesulphonate. By the reduction of these peroxides to the corresponding active alcohols by methods (see above) which were assumed not to affect the asymmetric centre of the molecule, it was shown in both cases that the oxidation reactions involved a high degree of stereochemical inversion, and therefore followed an S_N2 mechanism.

Further studies on the stereochemical course of the preparation and reactions of organic peroxides are in progress. We have obtained evidence that the S_Ni mechanism may be of importance in the oxidation of some alcohols and carboxylic esters.

Experimental

Unless otherwise stated, all values of α_D of liquids were recorded on the undiluted specimens in 1-dm. tubes at temperatures between 18° and 22°.

1-Phenylethanol (I) was resolved by Downer and Kenyon's method.[10]

Active 1-Phenylethyl Hydroperoxide (II).—In a typical experiment, a mixture of optically active 1-phenylethanol (3·0 g.) and 90% hydrogen peroxide (12 c.c.) containing concentrated sulphuric acid (0·1 g.) was stirred for 1 hr. at 0° and then for 5 hr. at room temperature; precautions were taken against explosion. Water (50 c.c.) was added, the product extracted three times with ether (5 c.c.), and the extract washed with saturated aqueous sodium hydrogen carbonate and with water, and dried (Na_2SO_4). The ether was removed at the pump and the residue distilled, yielding optically active *1-phenylethyl hydroperoxide* (2·76 g.), b. p. 66°/0·5 mm. (Found : C, 70·2; H, 6·9. $C_8H_{10}O_2$ requires C, 69·8; H, 7·3%).

This preparation was repeated a number of times on this scale partly because the hydroperoxide slowly decomposed, but more particularly to minimise the explosion hazard. The results are recorded in Table 2.

Table 2.

1-Phenylethanol (I)		1-Phenylethyl hydroperoxide (II)			Retention of configurational purity, %
Weight (g.)	α_D	Weight (g.)	α_D	α_{II}/α_I	
2·00	+43·30°	1·4	−4·80°	−0·111	−3·5
2·00	−43·30	1·40	+5·20	−0·120	−3·8
3·50	−41·80	3·20	+4·41	−0·105	−3·3
2·00	,,	1·69	+4·16	−0·101	−3·1
1·00	,,	0·79	+4·14	−0·099	−3·1
5·00	+14·20	4·10	−1·53 (*a*)	−0·108	−3·4
4·00	,,	3·64	−1·87	−0·132	−4·2
2·50	,,	2·10	−2·05	−0·144	−4·6
2·50	,,	2·10	−1·58	−0·111	−3·5
8·00	,,	6·40	−1·39 (*b*)	−0·098	−3·1
2·00	,,	1·40	−0·98	−0·069	−2·2

Specimens *a* and *b* were combined, giving the hydroperoxide, α_D^{18} −1·45°, which was used in some of the following experiments.

Active 1-Phenylethyl Triphenylmethyl Peroxide (IV).—(i) Triphenylmethanol (1·90 g.) in acetic acid (10 c.c.) containing concentrated sulphuric acid (0·1 g.) was added to 1-phenylethyl hydroperoxide (0·83 g.; α_D^{18} − 1·45°) in acetic acid (10 c.c.). After 2 hr., iced water was added, and active *1-phenylethyl triphenylmethyl peroxide* (IV) (2·35 g.) was obtained, m. p. 73—77°, $[\alpha]_D^{21}$ −0·94° (*l*, 2; *c*, 5·8 in $CHCl_3$). Recrystallisation from ethanol effected partial separation of the less soluble, higher melting, peroxide, m. p. 76—78°, $[\alpha]_D^{22}$ −0·64° (*l*, 1; *c*, 6·5 in $CHCl_3$), from the more active compound, m. p. 60—63°, $[\alpha]_D^{22}$ −2·63° (*l*, 0·5; *c*, 4·6 in $CHCl_3$). From a second recrystallisation of the fraction, m. p. 76—78°, the racemic peroxide was obtained, m. p. 85° (Found : C, 85·2; H, 6·2. Calc. for $C_{27}H_{24}O_2$: C, 85·2; H, 6·35%).[13]

The preparation was repeated with the following results :

(ii) The hydroperoxide, α_D^{18} −1·87° (3·64 g.), gave the peroxide (9·93 g.), m. p. 79—81°, $[\alpha]_D^{14}$ −1·21° (*l*, 2; *c*, 4·95 in $CHCl_3$).

(iii) The hydroperoxide, α_D^{21} +5·20°, gave the peroxide, m. p. 78—83°, $[\alpha]_D^{18}$ +4·3° (*l*, 0·5; *c*, 5·3 in $CHCl_3$), which on recrystallisation from ethanol gave a more soluble fraction, $[\alpha]_D^{17}$

[13] Cf. Davies, Foster, and White, *J.*, 1954, 2200.

+21·1°, m. p. 78—83°, and a less soluble fraction, m. p. 85—86°, $[\alpha]_D^{15}$ +2·6° (*l*, 0·5; *c*, 0·3 in $CHCl_3$).

(iv) The hydroperoxide, α_D^{21} −2·05° (1·25 g.), gave the peroxide (3·05 g.), $[\alpha]_D^{18}$ −1·35° (*l*, 2; *c*, 4·82 in $CHCl_3$).

Active 1-*Phenylethyl* 9-*Xanthenyl Peroxide.*—(i) The hydroperoxide (1·61 g.), α_D^{18} −1·45°, in acetic acid (5 c.c.) was added to xanthhydrol (2·3 g.) in acetic acid (10 c.c.). After 1·5 hr. the mixture was poured on ice–water (50 c.c.) yielding *active* 1-*phenylethyl* 9-*xanthenyl peroxide* (3·3 g.), m. p. 81—84°, $[\alpha]_D^{16}$ −0·72° (*l*, 2; *c*, 5·50 in $CHCl_3$). Recrystallisation from light petroleum gave the pure (±)-peroxide, m. p. and mixed m. p. 84—86°, and a more soluble fraction of the (−)-peroxide, m. p. 82—84°, $[\alpha]_D^{21}$ −1·03° (*l*, 0·5; *c*, 5·8 in $CHCl_3$).

(ii) In a second experiment the hydroperoxide, α_D^{21} +5·20°, gave the peroxide, m. p. 79—82°, $[\alpha]_D^{17}$ +4·2° (*l*, 0·5; *c*, 4·6 in $CHCl_3$), which by recrystallisation was separated into two fractions: (*a*) m. p. 84—86°, $[\alpha]_D^{15}$ +2·5° (*l*, 0·5; *c*, 2·9 in $CHCl_3$), and (*b*) m. p. 81—84°, $[\alpha]_D^{15}$ +6·7° (*l*, 0·5; *c*, 0·3 in $CHCl_3$).

Optical Stability of 1-*Phenylethyl Hydroperoxide under Preparative Conditions.*—The active hydroperoxide (0·79 g.), α_D^{20} +4·14°, n_D^{20} 1·5251, was stirred for 30 min. with 90% hydrogen peroxide (5 c.c.) containing concentrated sulphuric acid (0·1 g.). The hydroperoxide (0·68 g.) was recovered in the usual way, and had b. p. 50°/0·001 mm., α_D^{16} +3·94°, n_D^{20} 1·5246.

Reductions of Active 1-*Phenylethyl Hydroperoxide.*—(i) *With sodium sulphite.* The hydroperoxide (II; 2·0 g.), α_D^{18} −1·45°, was shaken for 6 hr. with a solution of sodium sulphite heptahydrate (9·0 g., 2·5 mols.; in 70 c.c. of water). The alcohol was extracted with ether, and the extract washed and dried, yielding 1-phenylethanol (III; 1·3 g.), b. p. 134—137°/120 mm., α_D^{17} −0·42°, characterised as its hydrogen phthalate, m. p. 106—108°. In a second experiment the hydroperoxide (1·49 g.), α_D^{21} +5·20°, gave the alcohol (0·7 g.), α_D^{21} +1·60°, b. p. 95—98°/20 mm. n_D^{20} 1·5265.

(ii) *With lithium aluminium hydride.* The hydroperoxide (1·0 g.), α_D −1·58°, in ether (5 c.c.) was added dropwise to a stirred suspension of lithium aluminium hydride (0·31 g., 1·1 mol.) in ether (10 c.c.) and a vigorous reaction took place. The mixture was then heated under reflux for 30 min., and the metal salts decomposed by the addition of water and then dilute sulphuric acid. From the ethereal layer, 1-phenylethanol was recovered (0·78 g., 88%), b. p. 112°/15 mm., α_D^{16} −0·40°, and characterised as its hydrogen phthalate, m. p. 108°.

(iii) *With zinc and acetic acid.* Zinc dust (2·0 g.) was added to a solution of the hydroperoxide (1·4 g.), α_D^{22} −0·98°, in glacial acetic acid (5 c.c.). No reaction had occurred after 30 min., and the solution still gave a positive test for peroxide (potassium iodide–starch). On addition of water (1 c.c.; dropwise) to the cooled mixture a vigorous reaction took place, and the solution no longer contained peroxide. The mixture was poured into water (50 c.c.), neutralised with sodium hydrogen carbonate, and filtered from excess of zinc, and the filtrate extracted with ether. The washed, dried extract yielded 1-phenylethanol (1·05 g.), b. p. 89—90°/1 mm., α_D^{16} −0·27°.

(iv) *With stannous chloride.*[14] The hydroperoxide (1·0 g.), α_D^{20} +4·41°, in acetic acid (5 c.c.) was added to approximately 0·5N-stannous chloride solution (5·65 g. of $SnCl_2,2H_2O$; 7·5 c.c. of concentrated hydrochloric acid; 92·5 c.c. of water). After 6 hr. at room temperature the solution was extracted with ether (3 × 5 c.c.). The combined extracts were washed with saturated aqueous sodium hydrogen carbonate and with water, and dried; distillation gave 1-phenylethanol (0·62 g.), α_D^{20} +1·41°, n_D^{23} 1·5249.

(v) *With sodium toluene-*p*-sulphinate.* The hydroperoxide (0·8 g.), α_D^{20} +4·41°, in ether (5 c.c.) was shaken with a solution of sodium toluene-*p*-sulphinate (2·58 g., 2 mols.) in water (30 c.c.). The organic layer still gave a strong peroxide test; pyridine (2 c.c.) was added and the shaking continued for a further 2 hr.; no peroxide then remained. The mixture was neutralised with dilute sulphuric acid and extracted with ether. Distillation gave 1-phenylethanol (0·43 g.), α_D^{19} +1·44°, n_D^{20} 1·5253.

(vi) *With hydrogen over platinum.* The hydroperoxide (0·79 g.), α_D^{21} −2·05°, in ether (15 c.c.) was shaken in an atmosphere of hydrogen in the presence of reduced platinum oxide (0·06 g.). After a rapid initial reaction the theoretical volume of hydrogen (128 c.c. at S.T.P.) was absorbed during 4 hr. 1-Phenylethanol was recovered in quantitative yield, b. p. 102—104°/14 mm., α_D^{18} −0·58°, n_D^{20} 1·5250.

The hydroperoxide was recovered in 45% yield after being shaken for 6 hr. with an excess of a 25% aqueous solution of sodium nitrite in the presence of a little ether to increase the mutual solubility of the phases.

[14] Cf. Barnard and Hargreaves, *Analyt. Chim. Acta*, 1951, **5**, 476.

Other Reactions of 1-*Phenylethyl Hydroperoxide.*—(i) *With* 2-*aminoethanol.* A mixture of aminoethanol (8 g., 6 mols.) and 1-phenylethyl hydroperoxide (2·0 g., 1 mol.) was warmed to 70°; a vigorous reaction occurred, the internal temperature rising to 120°. After a further 15 min. at 70° the reaction mixture, which then gave no test for peroxide, was poured on an excess of ice–dilute sulphuric acid. An ethereal extract yielded acetophenone (1·3 g.), b. p. 102°/14 mm. (semicarbazone, m. p. and mixed m. p. 201—203°).

(ii) *With sulphur dioxide at* pH 0 *and* 1. A violent reaction occurred when the hydroperoxide (1·5 g.) in ether (3 c.c.) was added dropwise to 1N-hydrochloric acid (50 c.c.) saturated with sulphur dioxide at 0°. After 2 hours' stirring, the mixture was extracted with ether, yielding an oil, b. p. 92°/12 mm. (0·6 g.), which gave a semicarbazone, m. p. 201—203°, undepressed on admixture with acetophenone semicarbazone. A similar result was obtained at pH 1.

(iii) *With sulphur dioxide at* pH 4·8. Acetic acid (*ca.* 12 c.c.) was added to a solution of sodium sulphite heptahydrate (7·5 g.) and sodium acetate trihydrate (1·5 g.) in water (100 c.c.), giving a mixture of pH 4·8. 1-Phenylethyl hydroperoxide (1·5 g.) in ether (5 c.c.) was added, and the mixture stirred for 3 hr. An ethereal extract yielded a mixture (0·95 g.) of acetophenone and 1-phenylethanol, which gave 1-phenylethyl *N*-phenylcarbamate, m. p. 93—94°, in 42% yield and acetophenone semicarbazone, m. p. and mixed m. p. 200—201°, in 40% yield.

Reductions of 1-*Phenylethyl Triphenylmethyl Peroxide.*—(i) *With zinc and acetic acid.* Zinc dust (5 g.) was added to a solution of 1-phenylethyl triphenylmethyl peroxide (4·93 g.), $[\alpha]_D^{14}$ −1·21° (*l*, 1; *c*, 4·9 in $CHCl_3$), in warm acetic acid (40 c.c.) and water (5 c.c.). After 30 min. at 80°, water was added and the solution made just acidic by successive additions of sodium hydroxide and a little hydrochloric acid. An ethereal extract yielded 1-phenylethanol (0·92 g.), b. p. 90—92°/15 mm., α_D^{18} −0·52°.

(ii) *With zinc and hydrochloric acid.* The peroxide (4·0 g.) in ethanol (96%; 20 c.c.) was reduced with zinc dust (4·0 g.) and concentrated hydrochloric acid (10 c.c.), at 50° to keep the peroxide in solution. When the metal was completely dissolved the mixture was steam-distilled, yielding 1-phenylethanol (0·6 g.), b. p. 70°/1·5 mm. (hydrogen phthalate, m. p. 103—105°, mixed m. p. 105—106°).

From an attempt to reduce 1-phenylethyl 9-xanthenyl peroxide with lithium aluminium hydride by a method similar to that described for 1-phenylethyl hydroperoxide, the peroxide (1·92 g. from 2·20 g.) was recovered, even when the period of heating of the reaction mixture was extended to 3 hr.[4] No reaction occurred with 1-phenylethyl triphenylmethyl peroxide under the same conditions.

Other Reactions of 1-*Phenylethyl Triphenylmethyl Peroxide.*—(i) *With sodium and ethanol.* The peroxide (2·8 g.) in dry ether (25 c.c.) was added to sodium powder (1·65 g.) under dry ether (25 c.c.). After 5 hr., 5 c.c. of the solution yielded 0·16 g. of the unchanged peroxide, m. p. and mixed m. p. 75—78°. (Kharasch, Fono, and Nudenberg[15] imply that reduction should have occurred by this stage; no reaction in fact takes place until alcohol is added. Their method of analysis of the products of the reaction of 1-methyl-1-phenylethyl 1-phenylethyl peroxide would apparently not distinguish between acetophenone and 1-phenylethanol.) Excess of 96% ethanol was added to the remainder of the mixture to dissolve the sodium. The product was poured on ice–water, and the ethereal layer washed and dried, yielding an oily solid. This was washed with light petroleum leaving impure triphenylmethanol (1·55 g.), m. p. 152—155°, mixed m. p. 155—157°. From the washings, acetophenone (0·3 g.) was recovered, b. p. 100°/17 mm. (semicarbazone, m. p. and mixed m. p. 202°).

(ii) *With sodium and methanol.* Methanol was added slowly to a solution of the peroxide (4·0 g.) in ether (50 c.c.) over sodium powder (1·6 g.). The ether was evaporated off and the residue distilled in steam. From the distillate, acetophenone (0·39 g.) was recovered. b. p. 84—88°/10 mm. (semicarbazone, m. p. 202°). The residue from the steam-distillation was impure triphenylmethanol (2·1 g.), m. p. 154—156°.

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[15] Kharasch, Fono, and Nudenberg, *J. Org. Chem.*, 1950, **15**, 753.

134. *The Dissociation Constant of the Ion-pair* $Co(NH_3)_6^{3+}OH^-$.

By J. A. Caton and J. E. Prue.

The value of the dissociation constant of $Co(NH_3)_6^{3+}OH^-$ has been obtained from the rate of decomposition of diacetone alcohol in solutions of hexamminocobalt trihydroxide. The physical significance of dissociation constants obtained in this way is discussed.

The depolymerisation of diacetone alcohol is specifically catalysed by hydroxyl ions and measurement of the rates of this reaction in solutions of hydroxides has been used [1] to obtain values of the concentration of free hydroxyl ions and thereby the dissociation constants of such species as $CaOH^+$ and TlOH. The values so obtained are in reasonable agreement with those derived by other methods.[2] As the extent to which covalent forces are responsible for the linking of ions such as Tl^+ and OH^- is uncertain,[3] the association of the hydroxyl ion with the ion $Co(NH_3)_6^{3+}$, in which the first co-ordination sphere of the cobalt atom is fully occupied by attached ligands, is of interest, and we have studied the rate of decomposition of diacetone alcohol in solutions of hexamminocobalt trihydroxide.

Experimental

Hexamminocobalt trichloride was prepared and purified as suggested by Palmer.[4] An approximately 0·15N-solution of the hydroxide was prepared by treating a solution of the chloride with an excess of silver oxide, but the solution obtained was unstable and slowly deposited cobaltic oxide. A fresh sample (250 ml.) was prepared for each kinetic measurement by using a column of Amberlite I.R.A. 400 anion-exchange resin, prepared as recommended by Nachod.[5] The chloride was roughly weighed out and dissolved in 100—150 ml. of water and the solution passed through the column at a rate not exceeding 4 ml./min. into a 250 ml. volumetric flask protected by a soda-lime tube. Water was then passed through the column until the flask was full. The kinetic measurement was made immediately and a sample of the freshly prepared solution was standardised simultaneously by potentiometric titration, a glass electrode being used, against standard hydrochloric acid solution made from constant-boiling acid. Identical titration curves were obtained for freshly prepared solutions made by the ion-exchange or the silver oxide method, or by mixing the hexamminocobalt trichloride and potassium hydroxide. This shows that the complex cobalt cation is not attacked by the hydroxyl ion in its passage through the resin.

The kinetic measurements were made at 25° ± 0·01° in dilatometers similar to that described by Halberstadt, Hughes, and Ingold.[6] The concentration of diacetone alcohol was about 4%. Rate constants were calculated by Guggenheim's procedure. Some measurements on solutions of sodium and potassium hydroxides confirmed the results of Bell and Prue.[1]

Results and Discussion

Table 1 gives the observed values of the first-order rate constant k, $[OH^-]^*$ being the stoicheiometric concentration of hydroxyl ions. The results were analysed in the same way as those for calcium hydroxide.[1] Extrapolation of the catalytic constant for the cobalt base to infinite dilution confirmed the value of $k/[OH^-] = 0{\cdot}502_5$ min.$^{-1}$ mole^{-1} l. previously found for the true catalytic constant. We therefore calculated the free hydroxyl-ion concentrations, $[OH^-]$, using this value. Now $[Co(NH_3)_6OH^{2+}] = [OH^-]^* - [OH^-]$, it being assumed that association beyond the first stage does not occur, and the values of the concentration dissociation quotient, Q, are given by

$$Q = [Co(NH_3)_6^{3+}][OH^-]/[Co(NH_3)_6OH^{2+}]$$

[1] Bell and Prue, *J.*, 1949, 362
[2] Bell and George, *Trans. Faraday Soc.*, 1953, **49**, 619.
[3] George, Rolfe, and Woodward, *ibid.*, p. 375.
[4] Palmer, "Experimental Inorganic Chemistry," Cambridge Univ. Press, 1954, p. 530.
[5] Nachod, *Analyt. Chem.*, 1952, **24**, 1027.
[6] Halberstadt, Hughes, and Ingold, *J.*, 1950, 2441.

TABLE 1.

$10^3[OH^-]$ * (mole l.$^{-1}$)	$10^3k/2{\cdot}303$ (min.$^{-1}$)	$10^3[OH^-]$ (mole l.$^{-1}$)	$10^3[Co(NH_3)_5OH^{2+}]$ (mole l.$^{-1}$)	$10^3[Co(NH_3)_6^{3+}]$ (mole l.$^{-1}$)	10^3Q (mole l.$^{-1}$)	10^3I (mole l.$^{-1}$)	$-\log_{10} K$
5·880	11·04	5·06	8·22	11·38	7·00	9·29	1·86
4·900	9·22	4·22	6·74	9·59	6·01	7·78	1·88
4·257	7·86	3·60	6·56	7·63	4·19	6·55	(1·99)
4·098	7·91	3·62	4·73	8·93	6·84	6·78	1·78
3·725	7·08	3·25	4·78	7·64	5·19	6·02	1·88
3·466	6·70	3·07	3·95	7·60	5·89	5·75	1·81
2·080	4·07	1·86	2·16	4·77	4·12	3·51	1·86
1·639	3·28	1·50	1·37	4·09	4·48	2·86	1·78
1·040	2·08	0·95	0·84	2·62	2·98	1·83	1·88

We assume that the activity coefficient of a z-valent ion at an ionic strength I is given by an expression of the form

$$-\log_{10} f_z = 0{\cdot}50\, z^2 I^{\frac{1}{2}}/(1 + I^{\frac{1}{2}}) + BI \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and accordingly define a tentative thermodynamic dissociation constant K by

$$\log_{10} K = \log_{10} Q - 3{\cdot}0\, I^{\frac{1}{2}}/(1 + I^{\frac{1}{2}}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

With one exception the values of K are constant within the limits of experimental error and show no trend with concentration so the effect of the term linear in I in equation (1) is in this case negligible. An average value gives $K = 0{\cdot}014$ mole l.$^{-1}$.

It is interesting to see whether the observed dissociation constant for the ion-pair corresponds to a reasonable value for the distance of closest approach of ions, assuming their interactions are adequately described by Bjerrum's model.[7] According to this model we regard pairs of ions of opposite charge approaching more closely than a distance q as single molecules and quantitatively the dissociation constant K of these ion pairs is given by

$$K^{-1} = 4\pi N\rho(2q_1)^3 \int_{2q_1/q}^{2q_1/a} e^y y^{-4} dy \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where ρ is the density of the solvent, $q_1 = z_1 z_2 e^2/2DkT$ and a is the distance of closest approach of ions which are paired. Bjerrum only treated the case where $q = q_1$; the effect of alternative choices of q has been examined recently by Brown and Prue.[8]

We now examine more closely the assumptions implicit in our calculation of K from the kinetic data. If the activity coefficient of the diacetone alcohol is effectively unity in dilute solution, the rate constant is given by

$$k = k_0 f_{M,OH}/f_{M,X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $f_{M,OH}$ and $f_{M,X}$ are stoicheiometric activity coefficients relating to the hydroxide and the activated complex. We ascribe any deviation from unity of the stoicheiometric activity coefficient factor to the incomplete dissociation of the metal hydroxide and thus relate the dissociation constants to deviations from a standard activity coefficient $f_{M,X}$. From Stuart models we estimate the radius of the activated complex ion as about 4 Å and if we assume a radius of 1·5 Å for the cation our standard activity coefficient will be, according to the Debye–Hückel theory

$$-\log_{10} f_{M,X} = AI^{\frac{1}{2}}/[1 + (qI^{\frac{1}{2}}/a^\circ)] \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where A and a° are constants and $q = 4$ Å $+ 1{\cdot}5$ Å $= 5{\cdot}5$ Å. Thus cation and hydroxyl ions approaching more closely than 5·5 Å are treated as associated, since this causes $f_{M,OH}$ to be less than $f_{M,X}$. Now q_1 has the values 3·6, 7·2, and 10·8 Å for 1–1, 2–1, and 3–1-valent electrolytes respectively. Therefore in the case of this particular reaction the kinetic method probably overestimates the association relevant to application of equation (3) with $q = q_1$ for singly charged cations such as Tl^+ and underestimates it in other cases. In Table 2 we compare values of a calculated from equation (1) for different values of the

[7] Bjerrum, *Kgl. danske Videnskab. Selskab*, 1926, **7**, No. 9.
[8] Brown and Prue, *Proc. Roy. Soc.*, 1955, *A*, **232**, 320.

integration limits, with crystallographic values. A value of 2·5 Å was obtained for the crystallographic radius of the ion $Co(NH_3)_6^{3+}$ by subtracting the radius of the iodide ion from the closest distance [9] of approach (4·7 Å) of Co and I in the crystal of $Co(NH_3)_6I_3$.

TABLE 2.

Ion pair	K (mole l.$^{-1}$)	a (Å) $q = \frac{1}{2}q_1$	$q = q_1$	$q = 2q_1$	cryst.
Tl^+OH^-	0·38	—	1·2	4·1	2·8
$Co(NH_3)_6^{3+}OH^-$	0·014	3·0	3·7	—	3·9

The values of a are markedly dependent on the integration limits; for $q \simeq 5·5$ Å ($1\frac{1}{2}q_1$ for thallous hydroxide and $\frac{1}{2}q_1$ for the cobalt base) they differ little from the crystallographic values. Bell and Prue's [1] previous conclusion concerning thallous hydroxide that, because the value of a calculated from Bjerrum's theory ($q = q_1$) is considerably smaller than the crystallographic value, covalent forces must be involved in the linking of Tl^+ and OH^- is probably unjustified. This explains George, Rolfe, and Woodward's [3] failure to detect any new Raman line due to associated thallous hydroxide.

READING UNIVERSITY. [*Received, September 22nd*, 1955.]

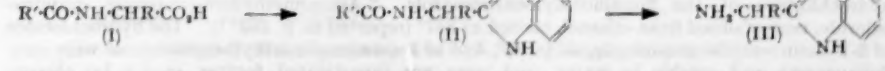
[9] Meisel and Tiedje, *Z. anorg. Chem.*, 1927, **164**, 223.

135. *The Preparation of Benziminazoles from α-Benzamido-acids and Peptides.*

By R. CRAWFORD and J. T. EDWARD.

Exploratory studies have been made on the identification of the *C*-terminal amino-acid residues of peptides as benziminazole derivatives.

HUGHES and LIONS [1] reported that fusion of hippuric acid (I; R = H, R′ = Ph) with *o*-phenylenediamine at 160° gave in good yield 2-benzamidomethylbenziminazole (II; R = H, R′ = Ph), which could be hydrolysed to 2-aminomethylbenziminazole (III; R = H). However, Lettré, Fritsch, and Porath [2] obtained α-benzamido β-2-benziminazolylpropionic acid in only 5·5% yield from *N*-benzoylaspartic acid, the α-carboxyl group



of this compound being unreactive under these conditions. In order to assess the feasibility of using the reaction sequence (I) ⟶ (II) ⟶ (III) to convert the *C*-terminal amino-acid residues of peptides into their benziminazole derivatives, we have studied the reactions of hippuric acid, *N*-benzoylalanine (I; R = Me, R′ = Ph), and *N*-benzoylphenylalanine (I; R = CH_2Ph, R′ = Ph). The compounds in the order named required increasingly drastic conditions to force condensation with *o*-phenylenediamine (see Experimental). The reactions are accelerated by acid catalysts, but these are undesirable for general use because of the acid-lability of some peptide linkages.[3]

The hydrochlorides of the aminoalkylbenziminazoles (III; R = H, Me, and CH_2Ph), derived from glycine, alanine, and phenylalanine, respectively, were obtained by hydrolysis of benzamido-compounds and were readily distinguished by paper chromatography.

Benzoylglycylglycine (I; R = H, R′ = PhCO·NH·CH_2) on fusion with *o*-phenylenediamine afforded the benziminazole (II; R = H, R′ = PhCO·NH·CH_2). On hydrolysis this gave glycine and 2-aminomethylbenziminazole, detected by paper chromatography, in

[1] Hughes and Lions, *J. Proc. Roy. Soc., N.S.W.*, 1938, **71**, 209.
[2] Lettré, Fritsch, and Porath, *Chem. Ber.*, 1951, **84**, 719.
[3] Christensen, *Compt. rend. Trav. Lab. Carlsberg*, 1953, **28**, 265.

approximately equimolar amounts. The same products were obtained, in the expected relative amounts, from glycylglycine (I; R = H, R′ = $NH_2 \cdot CH_2$) and from diglycylglycine (I; R = H, R′ = $NH_2 \cdot CH_2 \cdot CO \cdot NH \cdot CH_2$); the intermediate benziminazoles (II; R = H, R′ = $NH_2 \cdot CH_2$) and (II; R = H, R′ = $NH_2 \cdot CH_2 \cdot CO \cdot NH \cdot CH_2$) were very soluble in water, and were not isolated analytically pure. The behaviour of peptides contrasts with that of α-amino-acids, which do not form benziminazoles when fused with *o*-phenylenediamine.[1]

Experimental

Preparation of Benzamidoalkylbenziminazoles.—(a) *Without catalyst.* The benzamido-acid (1 mole) was heated with *o*-phenylenediamine (2 moles) in a sealed tube under the conditions tabulated below. These conditions represent the optimal discovered; lower temperatures or shorter reaction times resulted in lower yields.

Starting material	Reaction Temp.	Reaction Time (hr.)	Product	Yield (%)	M. p.	Formula	Analysis	C (%)	H (%)
N-Benzoylglycine	118°	10	2-Benzamidomethylbenziminazole	77	228° [a, c]	$C_{15}H_{13}ON_3,H_2O$	Found:	66·5	5·5
							Calc.:	66·8	5·5
N-Benzoylalanine	137	10	2-1′-*Benzamidoethylbenziminazole*	53	254° [b]	$C_{16}H_{15}ON_3$	Found:	71·8	5·6
							Reqd.:	72·4	5·6
N-Benzoylphenylalanine	250	3·5	2-α-*Benzamidophenethylbenziminazole*	65	237° [c]	$C_{22}H_{19}ON_3$	Found:	77·0	5·4
							Reqd.:	77·4	5·6

[a] Crystallized from aqueous ethanol. [b] Crystallized from ethyl acetate. [c] Reported m. p. 230°.[1]

(b) *With acid as catalyst.* The benzamido-acid (1 mole), *o*-phenylenediamine (2 moles), concentrated hydrochloric acid (2 moles), and 75% phosphoric acid (2 moles) were heated in a sealed tube for 10 hr. At 100°, the yield of 2-benzamidomethylbenziminazole was 73%, that of 2-1′-benzamidoethylbenziminazole, 91%. At 110°, the yield of 2-benzamidomethylbenziminazole was 94%.

Convenient derivatives were: *2-benzamidomethylbenziminazole picrate*, m. p. 248° (Found: C, 52·6; H, 3·6. $C_{21}H_{16}O_8N_6$ requires C, 52·5; H, 3·3%); *2-1′-benzamidoethylbenziminazole picrate*, m. p. 199° (Found: C, 53·0; H, 3·9. $C_{22}H_{18}O_8N_6$ requires C, 53·4; H, 3·6%); and *2-α-benzamidophenethylbenziminazole picrate*, m. p. 221° (Found: C, 58·8; H, 4·0. $C_{28}H_{22}O_8N_6$ requires C, 58·8; H, 3·8%).

Chromatographic Identification of the 2-Aminoalkylbenziminazoles.—The 2-benzamidoalkylbenziminazoles were hydrolysed with boiling 12N-hydrochloric acid (10 parts) for 5 hr. Benzoic acid was removed with ether; the aqueous solutions on evaporation to dryness afforded the hydrochlorides of the 2-aminoalkylbenziminazole. 2-Aminomethylbenziminazole dihydrochloride, recrystallised from ethanol, melted at 267° (reported m. p. 263° [1]). The hydrochlorides of 2-1′-aminoethylbenziminazole, m. p. 85°, and of 2-α-aminophenethylbenziminazole were very deliquescent and soluble in water, and were not investigated further except by chromatography on Whatman No. 1 filter paper. The benziminazoles were located as golden-yellow zones by spraying the chromatogram with an ethanolic solution of ninhydrin and heating. R_F values for the hydrochlorides are shown below.

Solvent system	(III; R = H)	(III; R = Me)	(III; R = CH_2Ph)
Butanol saturated with 2% aqueous hydrochloric acid	0·18	0·59	0·73
Pyridine–butanol–ethanol–water 12 : 66 : 4 : 8 (by vol.)	0·54	0·70	0·94
Pyridine–ethanol–water 12 : 80 : 8 (by vol.)	0·55	0·84	1·0

2-Hippuramidomethylbenziminazole (II; R = H, R′ = $PhCO \cdot NH \cdot CH_2$).—Benzoylglycylglycine (1 g.) and *o*-phenylenediamine (0·9 g.) were heated in a sealed tube at 137° for 10 hr. Crystallization of the melt from ethyl acetate gave white needles of *2-hippuramidomethylbenziminazole* (0·8 g.), m. p. 186° (Found: C, 66·2; H, 5·1. $C_{17}H_{16}O_2N_4$ requires C, 66·2; H, 5·2%). The *picrate* melted at 176° (Found: C, 52·4; H, 4·0. $C_{23}H_{19}O_9N_7$ requires C, 51·6; H, 3·6%). The benziminazole when hydrolysed with 12N-hydrochloric acid yielded glycine and 2-aminomethylbenziminazole in approximately equimolar amounts, as shown by paper chromatography.

Reactions of Glycylglycine and of Diglycylglycine with o-Phenylenediamine.—The di- and tripeptide (1 mole) were fused with *o*-phenylenediamine (2 moles) at 137° for 10 hr. No piperazine-2 : 5-dione (R_F 0·19) was detected in the melts by paper chromatography, propanol–water 1 : 1 (by vol.) being used as the developing agent, and the chlorine–starch–iodide method [4] for locating piperazine-2 : 5-dione. The melts were hydrolysed with hydrochloric acid, and glycine and 2-aminomethylbenziminazole identified by paper chromatography.

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TRINITY COLLEGE, DUBLIN. [*Received, October 3rd*, 1955.]

[4] Smith and Rydon, *Nature*, 1952, **169**, 922.

136. *An Ion-sieve Reagent for Cæsium–Alkali-metal Separations.*

By R. M. BARRER and D. C. SAMMON.

The use of silver analcite as an ion-sieve reagent for separations of sodium, potassium, and rubidium from cæsium has been investigated. The removal of sodium and potassium from mixtures with cæsium (all as chlorides) occurred quantitatively, and readily at about 100°, according to the equation

$$MCl + xAgA(s) \longrightarrow AgCl(s) + MAg_{(x-1)}A_x(s)$$

where A denotes the anionic framework of analcite and M is Na or K. In the removal of sodium, no cæsium entered the silver analcite and the method is suitable for quantitative analysis. In the potassium–cæsium separation a phase change occurs involving a minor rearrangement of the silver analcite to the potassium analcite (leucite) structure, and a little cæsium may be incorporated during this process: a correction is thus needed in quantitative analysis, but the method is available for the removal of K^+ from Cs^+. The rubidium–cæsium separation is more difficult and requires the use of methanol (or ethanol) as solvent; again a little cæsium may be incorporated during the phase change owing to modification of the silver analcite framework to the rubidium analcite one: the method may be useful, in certain circumstances, for purifications.

Hydrogen-ion exchange was observed when solutions of cæsium chloride, tetramethylammonium bromide, or tetraethylammonium iodide were treated with silver analcite:

$$H_2O + MX + xAgA(s) \longrightarrow AgX(s) + HAg_{(x-1)}A_x(s) + MOH.$$

By using the iodide this exchange was followed up to 60% completion. It can only proceed when the crystal acts as a sieve or semipermeable membrane towards the cations in solution and when the ion displaced is precipitated as an insoluble compound.

THE separation of the alkali metals in mixtures of their salts has remained an analytical problem of importance and is at its most difficult for separation of rubidium from cæsium. The cæsium may be precipitated [1] as complexes such as Cs_2PbCl_6, $Cs_3Sb_2Cl_9$, and Cs_2SnCl_6; the rubidium complexes are more soluble but the separation is not quantitative. The separation can be effected [2] by precipitating the cæsium with antimony and ferric chloride, to give a complex of approximate composition $4CsCl,4SbCl_3,FeCl_3$. The use of silicotungstic acid as a reagent for the complete separation of these elements has also been developed.[2]

Chromatographic methods have been investigated and quantities less than 1 mg. have

[1] Browning, "Introduction to the Rarer Elements," Wiley, London, 1917; Treadwell and Hall "Analytical Chemistry," Vol. I, Chapman and Hall, London, 1946.
[2] Scott, "Standard Methods of Chemical Analysis," Vol. I, Van Nostrand, New York, 1947.

been separated, by paper chromatography, by Miller and Magee [3] and by Steel.[4] Ion-exchange chromatography was used by Cohn and Kuhn [5] for separation of sodium and potassium and for partial separations of potassium, rubidium, and cæsium, on the H-form of Dowex 50; and Kayas [6] completely separated sodium, potassium, rubidium, and cæsium on Amberlite IR-100.

As no specific reagent has been found for quantitative separation of rubidium from cæsium there is good reason to develop further methods, especially any based on a new principle. Barrer [7] obtained no ion exchange on treating synthetic analcite (Na-form), leucite (K-analcite), or NH_4-analcite with solutions of cæsium chloride at temperatures above 200°. On the other hand exchange occurred with rubidium or potassium salts even at lower temperatures. In the present work, therefore, we have investigated the potentiality of analcite as a quantitative ion-sieve reagent for the separation of cæsium from the other alkali-metal ions. Radioactive ^{137}Cs is an important by-product of uranium fission,[8] so that its purification may be of growing interest. Analcite is only one of a number of materials which it is hoped to investigate for ion-sieve properties of use in cation separations. These materials have now been synthesised rather easily in these laboratories and include the zeolites analcite, phillipsite, harmotome, mordenite, chabazite, and faujasite, together with several new zeolites of barium, lithium, sodium, and rubidium; and also the ion-exchanging felspathoids leucite, nosean, sodalite, and cancrinite.*

Experimental

The analcite ($NaAlSi_2O_6.H_2O$) used in these experiments was part of a sample prepared [10] hydrothermally from a gel of analcite composition under alkaline conditions at 200°. This hydrothermal growth of analcite has been described elsewhere. Silver analcite ($AgAlSi_2O_6.H_2O$) was made by grinding the exchanger together with about ten times its weight of silver nitrate and heating the mixture at 220—230° in an open beaker in an electrically heated furnace. Two such fusions, each lasting about 4 hr., were performed. After each treatment the mixture was cooled and immersed in water to dissolve the salts. The exchanger was then filtered off, washed, and air-dried. The changes in weight of the exchanger between the first and the second fusions were very small compared with those due to the first, so that the two treatments give virtually 100% exchange.

Pure salts of the alkali metals and commercial (B.D.H.) tetra-alkylammonium halides were used. Chloride and iodide ion were estimated by the standard method with silver nitrate solution. Except in experiments reported in Tables 1 and 5, the degree of removal of salt by ion exchange was found by evaporating to dryness the filtrate from the reaction system, and weighing the residue. In all the experiments silver analcite was treated with a solution of one or more salts. Sealed glass tubes were used to contain the reactants in all the experiments except those described in Tables 1 and 5 and in parts of Tables 6, 7, and 10. Since these tubes were revolved in electric ovens the contents were kept thoroughly mixed. For some of the experiments described in Table 10 the reactants were heated under reflux and in the others (Tables 1, 5, 6, and 7) they were in covered beakers on the water-bath. In the last-mentioned method mixing was not so efficient but was probably adequate considering the duration of the treatments.

Optical examination of the exchange products was made with a Leitz research microscope, and *X*-ray powder photography by means of a Hilger HRX *X*-ray unit with 9 cm. cameras and Cu-$K\alpha$ radiation.

Results

In a first series of experiments (Table 1) silver analcite was treated on the water bath with solutions of alkali-metal chlorides:

$$MCl_{aq.} + xAgA(s) \rightleftharpoons AgCl(s) + MAg_{(x-1)}A_x(s) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

* Some of these results have been summarised by Barrer.[9] Others are as yet unpublished.

[3] Miller and Magee, *J.*, 1951, 3183.
[4] Steel, *Nature*, 1954, **173**, 315.
[5] Cohn and Kuhn, *J. Amer. Chem. Soc.*, 1948, **70**, 1886.
[6] Kayas, *J. Chim. phys.*, 1950, **47**, 1002.
[7] Barrer, *J.*, 1950, 2342.
[8] Cockcroft, *Roy. Inst. Chem. Monograph* No. 1, 1954.
[9] Barrer, Proc. Internat. Symp., "Reactivity of Solids," Gothenburg, 1952, p. 373.
[10] (*a*) Barrer, *Discuss. Faraday Soc.*, 1949, **5**, 326; (*b*) Barrer and White, *J.*, 1952, 1561.

where A represents the analcite framework. Because of the low solubility of silver chloride the reaction will proceed from left to right, unless an ion sieve effect supervenes so that the ion M^+ cannot diffuse into the analcite crystals; or unless, as is true of Li^+, the equilibrium very greatly favours the silver-rich form of the zeolite. The extent of reaction reported in Table 1 was

TABLE 1.

	LiCl		NaCl	KCl	RbCl	CsCl	
Salt (mg.)	20·9	20·9	23·4	21·3	20·8	23·0	23·0
Molar ratios AgA/MA	2·3	7·3	1·9	2·1	1·2	2·8	15·6
Time (hr.)	18	16	18	18	18	18	48
Cl removed (%)	74·1	87·2	99·2	99·1	26·2	7·0	36·0
Exchange of analcite (%)	32·2	11·9	52·2	47·2	21·8	—	—

estimated by the change in chloride content in the solution, the aqueous concentrations of alkali chloride being too low for formation of complexes such as $M[AgCl_2]$. For reasons discussed under hydrogen-ion exchange below, although with Cs^+ some Cl^- disappeared from solution this was accompanied, not by removal of Cs^+, but only by hydrolysis of cæsium chloride.

From Table 1 it is seen that extensive but not complete removal of Li^+ occurred under the experimental conditions used, that reaction with sodium and potassium was nearly complete, and that reaction with rubidium was incomplete. As will be seen later, there was no removal of cæsium ion

In a further series of experiments at 110° the blank correction to be applied to the weight of the evaporated filtrate from the reaction system was estimated as follows. A saline solution, or pure water, or water plus silver analcite was heated in glass tubes for various periods, and

TABLE 2. *Blank corrections.*

	Salt (mg.) (x)	Ag analcite (mg.)	Time (hr.)	Residue (mg.)	Residue − x (mg.)
RbCl	35·6	0	19	37·0	1·4
CsCl	46·0	0	16	47·6	1·6
—	0	0	0	1·4	1·4
—	0	0	24	0·8	0·8
—	0	0	24	1·8	1·8
—	0	166·3	24	1·4	1·4

the filtrate then evaporated to dryness to give the residue. The blank correction is this residue less the weight (x) of the original salt in the volume of water (5 ml.) taken. It is seen that this correction for a variety of conditions lies between 1 and 2 mg. In washing out reaction tubes, transference, and filtration, approximately 200 ml. of water were used in each experiment (cf. Tables 1—12).

A series of experiments was next conducted in which aqueous cæsium chloride was treated with silver analcite but the removal of the former was followed, not by estimation of chloride, but by weighing the total evaporated filtrate. The effect of a 5% conversion of cæsium chloride into cæsium hydroxide (cf. Table 5) would mean that this evaporation residue would be only 0·5% (or <0·25 mg.) less in weight than if no such exchange occurred. With the amounts of salt used (Table 3) this would be negligible. The weight of the residue less the weight (x) of cæsium chloride is to be compared with the blank corrections given in Table 2. Clearly

TABLE 3. *Treatment of cæsium chloride with silver analcite.*

CsCl (mg.) (x)	Ag analcite (mg.)	H_2O (ml.)	Time (hr.)	Temp.	Residue (mg.)	Residue − x (mg.)
51·2	149·8	10	24	95°	52·5	1·3
46·1	418·2	2	24	110	47·7	1·6
44·7	259·7	5	16	110	46·2	1·5
33·9	124·6	5	26	110	35·1	1·2

the removal of cæsium from the solution, by incorporation through ion-exchange into the silver analcite, is negligible. In considering Table 3 and the succeeding Tables it should be noted that the following weights of substances are approximately equivalent to each other and to silver analcite, if reaction as in equation (1) is complete: NaCl, 2·4 mg.; KCl, 3 mg.; RbCl, 5 mg.; CsCl, 7 mg.; AgA, 12 mg.

Since complete removal of rubidium chloride by ion exchange was not established in the experiment in Table 1, this was investigated more fully in experiments recorded in Table 4.

TABLE 4. *Incorporation of rubidium into silver analcite by ion exchange.*

Expt.	RbCl (mg.)	Ag analcite (mg.)	H_2O (ml.)	Time (hr.)	Temp.	Residue (mg.)
a	40·1	165·6	5	24	95°	9·7
b	40·7	251·5	5	24	95	2·6
c	40·6	331·2	5	24	95	1·4
d	40·4	280·5	5	16	95	2·5
e	40·4	277·4	5	41	95	1·6
f	40·4	258·2	5	18	85	4·7
g	39·6	268·8	5	24	110	2·2
h	40·3	252·8	5	27	110	1·6
h	40·3	354·8	2	24	110	2·6
—	35·2	248·8	5	23	110	2·3
—	154·9	1083·1	5	24	110	2·5

After each run, the filtrate was evaporated to dryness and weighed, to give the residue (column 7). Experiments *a*, *b*, and *c* show the effect of increasing the amount of exchanger; *d* and *e* the influence of duration of experiment; and *b*, *f*, and *g* the effect of temperature. In the most favourable cases (*c*, *e*, and *h*) the residue is no more than the blank correction, and the removal is therefore quantitative. It is thus evident that complete removal of sodium, potassium, and rubidium from their solutions can be effected, whereas no cæsium ions are removed.

Hydrogen-ion Exchange.—Before consideration of the separation of mixed solutions the important associated phenomenon of hydrogen-ion exchange must be discussed. This is connected with the removal of chloride ion from solutions of cæsium chloride in contact with silver analcite. This removal was studied by heating the silver analcite with cæsium chloride solutions on the water-bath for 18 hr. Successive treatments of four portions of the same analcite sample were given. The results are in Table 5. The formation of silver chloride could be observed visually, and silver chloride was removed between treatments with cold

TABLE 5. *Removal of* Cl^- *from cæsium chloride solutions.*

CsCl (mg.)	Molar ratio AgA/CsCl	Water (ml.)	Cl^- removed (%)	Cumulative H exchange (%) of Ag analcite
107·9	2·8	20	4·7	1·7
107·9	2·8	20	3·9	3·1
27·0	2·8	20	3·1	1·1
27·0	2·8	20	0·62	1·32
47·5	3·2	10	6·4	2·0
47·5	3·2	10	3·0	2·9
47·5	3·2	10	2·3	3·6
47·5	0·76	10	2·2	2·9
47·5	0·76	10	1·4	4·7
47·5	0·76	10	1·1	6·1

concentrated ammonia.* Since the cæsium was not removed (Table 3) but a proportion of the chlorine was, the reaction can be interpreted only as a hydrogen-ion exchange:

$$x\mathrm{AgA(s)} + \mathrm{CsCl} + \mathrm{H_2O} \rightleftharpoons \mathrm{AgCl(s)} + \mathrm{HAg_{(}}_{x-1}\mathrm{)A}_x\mathrm{(s)} + \mathrm{CsOH} \quad . \quad . \quad . \quad (2)$$

The cæsium ions cannot enter the crystals, and removal of silver ions from the lattice by precipitation as silver chloride is accompanied by an equivalent influx of hydrogen ions from the solution, provided by dissociation of water. The extent of hydrogen-ion exchange of the analcite is given in column 5 of the Table.

The hydrogen-ion exchange recorded in Table 5 is not extensive. However, further experiments were conducted, with aqueous tetramethylammonium bromide and tetraethylammonium iodide and silver analcite. Silver bromide and silver iodide were freely formed, the extent of reaction being promoted by the smaller solubility products of silver bromide and iodide as compared with that of the chloride. It was then shown in the following way that the removal of iodine as silver iodide was not accompanied by entry of NEt_4^+ into the analcite. The exchange product and silver iodide were filtered off, and the iodine in the filtrate was precipitated, by silver nitrate, as silver iodide, and weighed. Excess of silver was removed as silver chloride, and repeated evaporations to dryness with hydrogen chloride converted all the

* This treatment never exceeded 15 min. in duration. Treatment for an hour or more with the ammonia gave a loss in weight of the exchanger of 1—2%, after allowance for the silver chloride dissolved. If attributed only to exchange $Ag^+ \rightleftharpoons NH_4^+$ this would be <5% exchange. Such a marginal exchange should not affect the reaction between AgA and CsCl according to eqn. 2.

tetraethylammonium salt into the chloride. The tetraethylammonium chloride was finally dried at 120° to remove all or nearly all the excess of hydrochloric acid. The chloride-ion content was then determined as silver chloride : this was equivalent to a little more than the starting weight of tetraethylammonium iodide, but the small difference can be attributed to incomplete removal of hydrochloric acid from the salt. It was inferred that no NEt_4^+ was removed under conditions when more than 50% of the I^- was replaced from the solution, owing to H^+ replacing Ag^+ in the exchanger.

In these treatments of silver analcite with solutions of tetraethylammonium iodide, the exchanging solution developed a pH >10, in accordance with the reaction :

$$xAgA(s) + NEt_4I + H_2O \longrightarrow AgI(s) + HAg_{(x-1)}A_x(s) + NEt_4{\cdot}OH \quad . \quad . \quad (3)$$

The total alkalinity due to two treatments of a sample of silver analcite with aqueous tetraethylammonium iodide was measured by titration with N/100-hydrochloric acid. Eqn. 3 being assumed valid, the titre corresponded to replacement of 60% of the Ag^+ by H^+ in the analcite. Finally, when silver iodide was extracted from the $HAg_{(x-1)}A_x$ by cold potassium iodide solution, the presumed $HAg_{(x-1)}A_x$ was, as required, demonstrably much lighter than the original silver analcite. Heating tetraethylammonium iodide solutions alone produced a pH of 9·7, but alkalinity so developed was much smaller than that observed after reaction with silver analcite.

Processes of hydrogen-ion exchange due to ion-sieve activity have now been found in these laboratories with analcite, chabazite,[11] faujasite,[12] ultramarine,[13] cancrinite, and sodalite,[10b] and must be regarded as a general phenomenon associated with ion-sieve action. The H-ion exchange forms are the fully crystalline, zeolitic or felspathoid solid "acids." Where two cations are present in solution, of which one but not the other can enter the exchanger crystals, hydrogen-ion exchange will not occur, for at pH ~7 the hydrogen ions cannot compete for intracrystalline sites with the much greater concentration of that dissolved cation which can freely diffuse into the crystals. This point in most important for understanding of the ion-sieve separations of cationic species now to be described.

Separation of Sodium–Cæsium Chloride Mixtures.—Various mixtures of sodium and cæsium chloride and added solvent were treated with silver analcite under the conditions indicated in Table 6. The amount of sodium chloride removed was found by evaporation of the filtrate to dryness and weighing. The solvent was water except in the experiment marked * where methanol was used. The experiments were carried out in sealed tubes, except for that marked †

TABLE 6. *Separation of sodium–cæsium chloride mixtures.*

Ag analcite (mg.)	NaCl (mg.)	CsCl (mg.) (*x*)	Time (hr.)	Temp.	Solution (ml.)	Residue (mg.)	Residue − *x* (mg.)
136·6	13·5	103·9	24	110°	5	104·6	0·7
136·9	12·3	34·7	24	110	5	35·7	1·0
334·2	35·7	51·7	28	85	2	52·8	1·1
361·1	50·5	54·9	18	95	10 *	55·7	0·8
388·0	34·2	54·7	25	85	2 †	55·7	1·0

for which a covered beaker was the reaction vessel. The weights in column 8 are no more than the blank corrections in Table 2, and it may be concluded that every set of conditions recorded in Table 6 has led to quantitative removal of sodium from cæsium.

Separations of Potassium–Cæsium Chloride Mixtures.—Experiments designed to separate these mixtures were carried out in the same way as for the sodium–cæsium separation. The results are recorded in Table 7, where * and † have the same significance as previously. In the experiments marked ‡ the chloride contents of the residues were determined and were found to be slightly less than those of the original cæsium chloride. Either some hydrogen-ion exchange occurred with silver (cf. eqn. 2) after all the potassium had entered the crystals, or else a little cæsium was also incorporated. The negative values of the quantity (Residue − *x*) recorded in column 8 indicate that there is normally a slight removal of cæsium [since the blank determinations recorded in Table 2 lead us to expect a small positive value for (Residue − *x*)]. This phenomenon, encountered also with rubidium–cæsium chloride mixtures (Table 12), but not with sodium–cæsium chloride mixtures (Table 6), is discussed below.

The results recorded in Table 7 thus indicate quantitative removal of potassium from its mixtures with cæsium together with a very small incorporation of Cs^+ into the exchanger.

[11] Barrer and Sammon, unpublished work.
[12] Barrer and Buser, unpublished work.
[13] Barrer and Raitt, *J.*, 1954, 4641.

TABLE 7. *Separation of potassium–cæsium chloride mixtures.*

Ag analcite (mg.)	NaCl (mg.)	CsCl (mg.) (x)	Time (hr.)	Temp.	Solution (ml.)	Residue (mg.)	Residue − x (mg.)
126·5	14·1	35·4	24	110°	5	35·3	−0·1
126·7	14·0	37·0	24	110	5	36·2 ‡	−0·8
142·7	16·6	—	24	110	5	1·8	+1·8
144·5	12·5	—	4	110	5	1·4	+1·4
146·1	15·2	34·5	24	110	5	34·0 ‡	−0·5
274·0	51·3	68·1	18	95	10 *	67·1 ‡	−1·0
420·2	15·6	36·2	24	110	5	36·2	0·0
442·2	34·9	43·6	24	85	2	43·4	−0·2
499·9	38·6	54·8	24	85	2 †	54·0 ‡	−0·8

Separation of Rubidium–Cæsium Chloride Mixtures.—Mixtures of rubidium and potassium chloride with water (5 ml.) were first treated at 110° for 24 hr. in sealed tubes with varying proportions of silver analcite. The chlorides in the filtrate were determined as before, by evaporation to dryness and weighing (Table 8, column 5). An experiment without silver analcite gave a blank correction of 1·6 mg. (cf. Table 2), which was then subtracted from each residue (Table 8, column 6). Assuming negligible removal of cæsium chloride permits computation of the amount of rubidium chloride removed (column 7). The degree of separation increases as the amount of silver analcite increases up to a limiting figure of about 490 mg. However, quantitative separation was not achieved under the conditions reported in Table 8.

In a further study of this separation the rubidium and cæsium in the filtrate after reaction in sealed tubes at 110° were determined spectrochemically (we are indebted to Dr. R. L. Mitchell, of the Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, for the spectrochemical determinations). Results are shown in Table 9. Experiments marked *a* (column 6) show the effect of varying the volume of water; and those marked *b* the effect of changing the proportions of the two salts. Fluctuations in sign in column 5 indicate only that the spectrochemical method is not very accurate, but the results support the view that only rubidium is removed from solution. Smaller volumes of solvent give better separations, and these are also improved if rubidium chloride is present in equivalent or in greater quantity than cæsium chloride.

TABLE 8. *Partial separations of rubidium–cæsium chloride: varying* Ag *analcite proportions.*

Ag analcite (mg.)	RbCl (mg.)	CsCl (mg.)	Total salt (mg.)	Residue (mg.)	Residue − corrn.	RbCl removed (%)
139·0	23·0	37·4	60·4	54·6	53·0	32
257·3	24·3	33·6	57·9	48·5	46·9	45
362·8	23·9	36·8	60·7	44·7	43·1	73
490·0	24·6	40·1	64·7	44·8	43·2	87
498·9	24·3	34·3	58·6	39·2	37·6	86
622·4	24·8	34·7	59·5	40·6	38·4	85

TABLE 9. *Partial separations of rubidium–cæsium chloride: varying proportions of solvent and of* Rb : Cs *ratio.*

Ag analcite (mg.)	RbCl (mg.)		CsCl (mg.)		H_2O (ml.)	Time (hr.)
	Initial	Removed	Initial	Removed		
0	23·3	0·0	0	−2·5	5	44
0	0	0·0	34·6	+0·4	5	14
544·8	24·6	11·2	39·3	−1·2	10 *	24
484·0	23·8	13·2	36·8	+0·7	5 *	24
531·6	23·4	19·2	33·8 ᵇ	+1·5	2 *	24
494·0	24·2	21·7	16·3 ᵇ	+0·5	5	24
471·9	13·3	7·6	32·8 ᵇ	−0·1	5	24
471·5	23·7	18·8	33·2	−1·0	5	12
503·0	23·8	17·4	39·7	+0·4	5	48

Since the removal of rubidium chloride from cæsium chloride was still not quantitative, experiments were conducted with solvents other than water. These were carried out in sealed tubes, with the exception of those in Table 10 marked * in which the solvent was boiled under reflux sufficiently vigorously to keep the exchanger in suspension.

The blank correction was taken as 1·5 mg., and the results in the bottom two rows of Table 10 indicate that quantitative separations of Rb^+ and Cs^+ can be obtained in closed systems by using organic solvents, but not under reflux conditions. Evidently organic solvents are better than water in effecting this separation by the ion-sieve method. In order to compare the effectiveness of water and methanol a series of experiments was conducted at 110°, each for 24 hr.

TABLE 10. *Separations of rubidium–cæsium chloride : non-aqueous solvents.*

Ag analcite (mg.)	491·5	544·3	503·5	536·4	534·8	285·5	453·9
RbCl (mg.)	24·1	23·2	23·9	24·5	23·7	24·7	23·4
CsCl (mg.)	32·7	37·5	34·5	37·7	33·1	36·4	33·8
Solvent	MeOH	MeOH	EtOH	EtOH	EtOH *	PrⁿOH *	PrⁿOH *
(ml.)	5	5	2	2	5	5	5
Time (hr.)	120	24	24	24	24	21	24
Temp.	85°	110°	110°	110°	78°	97°	97°
Residue (mg.)	34·2	39·0	36·7	39·5	50·0	59·7	48·4
Residue — corrn. (mg.)	32·7	37·5	35·2	38·0	48·5	58·2	46·9
RbCl removed (%) ...	100	100	97	99	35	12	44

TABLE 11. *Rubidium–cæsium chloride separation : comparison of water and methanol as solvent.*

Ag analcite (mg.)	RbCl (mg.)	CsCl (mg.)	Solvent (ml.)	Residue (mg.)	Residue — corrn. (mg.)	RbCl removed (%)
Water						
552·3	23·3	38·5	1	43·5	42·0	85
547·8	24·1	34·1	2	40·4	38·9	80
550·9	22·9	32·8	5	40·5	39·0	73
Methanol						
517·4	24·5	40·1	1	42·4	41·9	93
535·8	23·7	35·3	2	38·8	38·3	87
494·8	24·0	34·5	5	38·4	37·9	86

under comparable conditions. The results presented in Table 11 show that more complete separation still occurs when methanol is solvent. In these experiments with water as solvent the ordinary distilled water was used for washing out and the blank correction was taken, as before, to be 1·5 mg., but when methanol was the solvent, de-ionised water was used, with the lower blank correction of 0·5 mg. The effectiveness of the separation with methanol is not the same in the experiments recorded in Tables 10 and 11. Since different batches of silver analcite had been employed it was thought possible that the method of preparation of the silver analcite could influence the results. Three different, but similarly prepared, batches of this ion-sieve reagent were then used, and it was demonstrated (Table 12) that differences in completeness of the separation did arise, when methanol was the solvent. The recorded removal of $>100\%$ of rubidium chloride at the bottom of column 5 means that some cæsium chloride had also been removed in this case. This behaviour is discussed below.

TABLE 12. *Rubidium–cæsium chloride separation : effect of different preparations of* Ag *analcite.*

Ag analcite (mg.)	Batch	RbCl (mg.)	CsCl (mg.)	RbCl removed (%)
494·8	A	24·0	34·5	86
491·5	B	24·1	32·7	100
507·0	C	24·1	35·6	106

One may conclude that conditions can be realised for complete removal of Rb^+ from Cs^+ by using silver analcite as an ion sieve, but that these conditions are more stringent than are those required for the separations of Na^+ and K^+ from Cs^+.

X-Ray Examination of the Exchanger.—In order to obtain information regarding the limited removal of cæsium chloride [Table 12 (Ag analcite C) and Table 7] in presence of rubidium or potassium chloride, but not in presence of sodium chloride, or in absence of other electrolyte, various cationic forms of the exchanger were subjected to *X*-ray powder photography. Sodium analcite of refractive index ~1·486, regenerated from silver analcite, gave an *X*-ray pattern with the same spacings and intensities as natural analcite; and a pattern with practically identical spacings but different intensities was also observed for silver analcite. For a product $Na_{0\cdot4}Ag_{0\cdot6}AlSi_2O_6.H_2O$ the pattern was in spacings the same as, and in intensity midway between, the patterns of the pure sodium and the pure sodium form respectively. Moreover, all these mixed crystals had a single refractive index of ~1·52. It is thus considered that no appreciable lattice change occurs during the Na ⇌ Ag exchange in analcite, and that the end members form a continuous series of solid solutions.

The *X*-ray diffraction pattern of potassium analcite (leucite) showed definite changes as compared with that of silver (or sodium) analcite. In an analcite of cationic composition K : Ag = 25 : 75 the diffraction pattern was very similar to that of silver analcite, but some of the

stronger lines of the leucite pattern were also superposed. Optical examination showed that crystals of two refractive indices were present, those of higher index being predominant. In an analcite of cationic composition K : Ag = 50 : 50, the *X*-ray pattern was similar to that obtained by superposing the separate patterns of leucite and of silver analcite. One may conclude from the optical and *X*-ray evidence that there is limited solid solubility of the pure end members potassium and silver analcite.

Finally, pure rubidium analcite gave a pattern with differences from those of the other pure cationic forms of the exchanger (Na, Ag, or K). The refractive index was ~1·526. An analcite of cationic composition Rb : Ag = 45 : 55 was then investigated. The sample was made up of a fine powder in admixture with unfractured crystallites of normal size. The diffraction pattern of the fine powder was similar to that of rubidium analcite, and the refractive index was $<1·53$. The pattern of the coarse fraction containing some fine powder was similar to that of silver analcite, with superposition of some rubidium analcite lines. The majority of the crystals had refractive index $>1·54$. As with sodium and silver analcite, it is thus evident that rubidium and silver analcites show limited mutual solid solubility. These results are comparable with those of Barrer and his co-workers.[7, 14, 15]

Discussion

Where limited solid solubility of the end members of an exchanging pair occurs, it has already been shown that hysteresis and nucleation phenomena occur.[15] Phase changes involving even minor rearrangements of the structural network often result in a high degree of ionic or molecular mobility during the process;[16] this enhanced mobility is, for example, the basis of the Hahn emanation method of following solid-state reactions. It therefore seems likely that a little cæsium can sometimes become incorporated in the new analcite phase during the phase transitions Ag-rich ⟶ K-rich, or Rb-rich, analcites. On the other hand, in the Na^+–Ag^+ exchange where there is continuous solid solubility without any phase change, no incorporation of cæsium can occur. We consider this to be the explanation of the limited uptake of cæsium into silver analcite when exchanging with aqueous rubidium or potassium chloride, but not when exchanging with aqueous sodium chloride, or when dissolved alone.

The presence of even a small amount of cæsium in the analcitic lattices may, moreover increase the difficulty of the final stages of exchange (*e.g.*, that of Rb^+ diffusing into the new Rb-rich phase) by blocking some of the diffusion paths along which the Rb^+ and residual Ag^+ must migrate. Such an effect will be more apparent the larger the migrating ion, and may then have a bearing upon the greater ease of effecting sodium–cæsium and potassium–cæsium separations compared with that of rubidium–cæsium.

The excellent sodium–cæsium separation, and the equally quantitative potassium–cæsium separation, leave only cæsium in the solution, and are readily accomplished. Methanol should be used for the rubidium–cæsium separation, and with different preparations of silver analcite three types of behaviour were observed: incomplete removal of rubidium chloride; complete removal of rubidium chloride; and complete removal of rubidium chloride with removal also of a little cæsium chloride. If a negligible amount of cæsium is removed in the first two cases, then rubidium may be freed from cæsium, since the rubidium which enters the silver analcite may be displaced again by ion exchange. In the third case, cæsium may be freed from rubidium, just as it may be freed from sodium and potassium. Thus if silver analcite could be made under such closely defined conditions that the extent of its reaction with rubidium chloride in admixture with cæsium chloride did not vary from sample to sample, then there would be the possibility of one of these two applications.

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[14] Barrer and Hinds, *J.*, 1953, 1879.
[15] Barrer and McCallum, *J.*, 1953, 4305.
[16] Cf. Buerger, *Amer. Miner.*, 1948, **33**, 101.

137. *Studies on Degraded Esparto Cellulose.*

By G. O. Aspinall and W. B. Fordyce.

Degraded esparto cellulose capable of peptisation into a colloidal solution in water has been prepared. Methylation end-group assay showed that the degraded cellulose had an average chain length of 77 ± 3 glucose residues, and a similar value was obtained from periodate oxidation. The chemical accessibility of esparto cellulose, before and after degradation, has been investigated by acid hydrolysis and water sorption methods.

The heterogeneous degradation of cellulose by hot dilute (*ca.* 10%) mineral acid causes severe depolymerisation usually accompanied by destruction of the characteristic fibrous structure. After a rapid initial decrease, the degree of polymerisation tends to reach a limiting value of the order of 50—200 with the formation of fragments relatively resistant to further attack under the conditions of hydrolysis. These resistant fragments, whose exact size depends on the source and previous treatment of the original cellulose,[1] are considered to arise from preferential hydrolysis of the amorphous regions of the cellulose fibre and to represent the more highly ordered or crystalline regions. Indeed, methods for the determination of the degree of crystallinity of celluloses are based on the relative ease of accessibility to chemical attack of the amorphous regions.[2] Rånby [3] has shown that some of these resistant fragments (or cellulose micelles) will peptise to form aqueous sols in the pH range 3·5—9·5 and in the absence of electrolytes. Electron-microscopic measurements showed that the dimensions of the micelles (*ca.* 500 × 80 Å) were similar to those of the ordered regions or crystallites of the long filamentary fibrils obtained by ultrasonic treatment of cellulose fibres;[3,4] the lengths of the micelles corresponded to the values for the degrees of polymerisation of the derived cellulose nitrates measured viscometrically. These cellulose micelles, however, had not been examined by chemical methods, and this paper describes the results of an investigation of such a degraded cellulose prepared from esparto grass (*Stipa tenacissima* L.).

Esparto cellulose, obtained by exhaustive extraction of the delignified grass with dilute alkali to remove hemicelluloses, was hydrolysed with hot dilute sulphuric acid, and cellulose sols were obtained by repeated washing of the resulting hydrocellulose with water. Peptisation occurred after the fourth or fifth washing, and the colloidal particles, which showed the hydrophobic properties described by Rånby,[3] coagulated in the presence of a small amount of added electrolyte. The degraded esparto cellulose was methylated with rigorous exclusion of oxygen [5] and the quantity of tetra-*O*-methyl-D-glucose isolated from the hydrolysis of the methylated cellulose corresponded to one terminal non-reducing group per 77 ± 3 glucose residues. Estimation of the formic acid produced on periodate oxidation [6] indicated an average chain length of 69—72, a figure in reasonable agreement with the value obtained from the methylation studies.

It is interesting that chromatographic evidence was obtained for the presence of small quantities of xylose in the hydrolysate from the degraded cellulose and of small quantities of 2 : 3 : 4-tri-*O*-methyl and 2-*O*-methyl xyloses in the hydrolysate from the methylated cellulose. These observations provide further evidence for the extremely close association between cellulose and hemicelluloses in the plant.[7] It would be premature, however, to speculate whether this association is purely physical or whether chemical linkages exist between the two components.

Determinations of chemical accessibility, by two methods, were carried out on three cellulose samples: (1) the original esparto cellulose, (2) the "colloidal" degraded esparto cellulose (referred to as degraded esparto cellulose), and (3) the residual insoluble degraded

[1] Jörgensen, *Acta Chem. Scand.*, 1950, **4**, 185.
[2] Nickerson, *Adv. Carbohydrate Chem.*, 1950, **5**, 103.
[3] Rånby, *Discuss. Faraday Soc.*, 1951, No. **11**, 158; *TAPPI*, 1952, **35**, 53.
[4] Rånby and Ribi, *Experientia*, 1950, **6**, 12.
[5] McGilvray, *J.*, 1953, 2577.
[6] Halsall, Hirst, and Jones, *J.*, 1947, 1399, 1427.
[7] Adams and Bishop, *Nature*, 1953, **172**, 28.

esparto cellulose which did not undergo peptisation during the preparation of the "colloidal" cellulose (hereinafter called esparto hydrocellulose). In the first method, Nickerson's hydrolytic oxidation procedure [8] was followed, and the carbon dioxide liberated when each cellulose was digested in a boiling solution of ferric chloride and hydrochloric acid was measured gravimetrically. The carbon dioxide evolved from an equivalent quantity of glucose was measured concurrently. The results were calculated by Nickerson's formula [8] on the assumption that the rapid initial hydrolysis was due to attack in the easily accessible or amorphous regions, whilst the subsequent slow hydrolysis was due to attack in the more highly ordered regions, which are penetrated by chemical reagents only with difficulty. Fig. 1 shows the evolution of carbon dioxide from glucose and from the three cellulose samples, and Fig. 2 shows the percentage of each cellulose hydrolysed plotted against time. The sharp change in rate of hydrolysis of the celluloses over the first 2 hr. is brought out more clearly when the rate is plotted against time (Fig. 3). The rapid initial hydrolysis is complete after 2—3 hr. and from the extrapolation of the percentage hydrolysis–time curves to zero time, values for the chemical accessibility of the celluloses were obtained. The values quoted were obtained from the 2—4 hr. period, and although the shapes of the curves do not permit an exact extrapolation, the relation between the three celluloses is indicated, namely, that the degraded cellulose is slightly less, and the hydrocellulose more, accessible than the original esparto cellulose.

Cellulose	Accessibility (%)	Cellulose (%) hydrolysed after 8 hr.
Esparto cellulose	8·4	21
Esparto hydrocellulose	8·5	34
Degraded esparto cellulose	8·2	19

In the second method, the sorption of water vapour by the cellulose samples was measured and Fig. 4 shows a typical plot of moisture regain against relative humidity. The uptake of water for any cellulose is a function of the accessibility, and calculations from the characteristic sigmoid-shaped isotherms were made by using the theoretical sorption isotherm of Hailwood and Horrobin.[9] Again the results show the degraded esparto cellulose to be less accessible than the original esparto cellulose, whilst the hydrocellulose was slightly more accessible. Although both series of experiments suggest that the degraded "colloidal" cellulose is slightly less accessible than the parent esparto cellulose, as would be expected if hydrolysis of the esparto cellulose preferentially removes the less ordered or amorphous regions, the similarity between the two samples is a more striking feature of the results. It is interesting that Hermans [10] has shown, using the *X*-ray

Cellulose	Regain at 50% relative humidity	Accessibility (%)
Esparto cellulose	6·22	35
Esparto hydrocellulose	6·14	36
Degraded esparto cellulose	5·78	31

diffraction method of Hermans and Weidinger,[11] that colloidal cellulose micelles prepared by Rånby's method [3] had the same degree of crystallinity as the wood pulp from which they were derived. On the other hand, the esparto hydrocellulose was less highly ordered and was attacked 2·5 times more rapidly than the "colloidal" cellulose during the later stages of the hydrolytic oxidation (Fig. 3). As the hydrophobic character of the cellulose sols may be attributed to the high lateral order and high degree of internal hydrogen bonding, the process of peptisation appears to favour the separation of the highly ordered particles from the less highly ordered hydrocellulose.

The results of this investigation show that the cellulose sols from the hydrolysis of esparto cellulose contain particles of the same order of magnitude as those isolated by Rånby [3] from a number of sources. The average chain length of the degraded esparto cellulose (77 $\pm$ 3) is intermediate between those found by Rånby for the degraded cellulose

[8] Nickerson, *Ind. Eng. Chem. Anal.*, 1941, **13**, 423.
[9] Hailwood and Horrobin, *Trans. Faraday Soc.*, 1946, **42**, *B*, 84.
[10] Hermans, *Makromol. Chem.*, 1951, **6**, 25.
[11] Hermans and Weidinger, *J. Polymer Sci.*, 1949, **4**, 135.

from wood pulps and from the corresponding mercerised wood celluloses. Although these resistant colloidal particles arise from the preferential hydrolysis of the amorphous regions of tle original cellulose, it is unlikeiy that they can be identified with the crystalline regions. On the one hand, it is not known how far the crystallite size may decrease during

FIG. 1. *Evolution of carbon dioxide from (I) glucose, (II) esparto hydrocellulose, (III) esparto cellulose, and (IV) degraded esparto cellulose in boiling* $FeCl_3$–HCl.

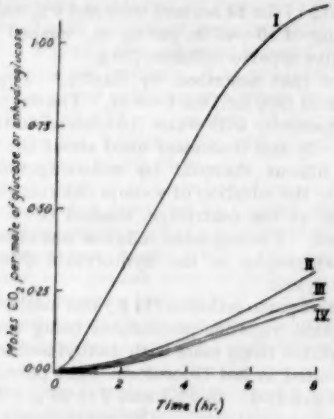


FIG. 2. *Hydrolysis–time curves for (I) esparto hydrocellulose, (II) esparto cellulose, and (III) degraded esparto cellulose.*

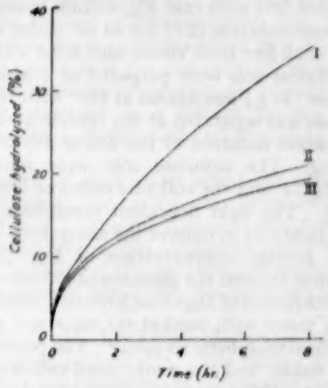


FIG. 3. *Rates of hydrolysis in* $FeCl_3$–HCl *of (I) esparto hydrocellulose, (II) esparto cellulose, and (III) degraded esparto cellulose.*

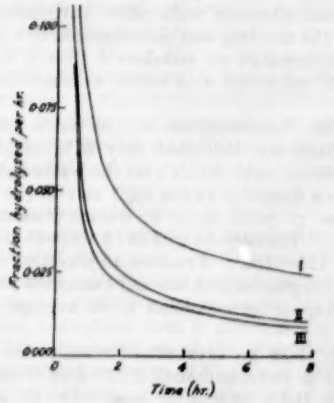
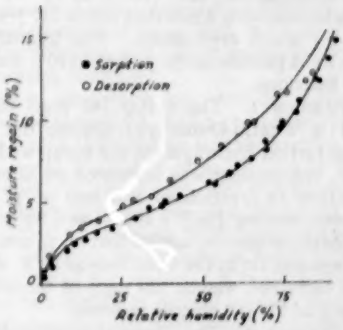


FIG. 4. *Typical water-vapour sorption–desorption isotherm for degraded esparto cellulose.*



the hydrolysis. On the other hand, there is evidence that as chain scission occurs a rapid crystallisation of the less ordered regions takes place causing an increase in size of the crystallites.[12–14] The fact that the isolated colloidal particles show little increase in degree of crystallinity (or correspondingly little decrease in accessibility) suggests that crystallite size, determining as it does the proportion of accessible glucose residues in the

[13] Hermans and Weidinger, *J. Polymer Sci.*, 1949, **4**, 317.
[13] Brenner, Frilette, and Mark, *J. Amer. Chem. Soc.*, 1948, **70**, 877.
[14] Howsmon, *Textile Res. J.*, 1949, **19**, 152.

surface layers of the cellulose particles, may be a more important factor in accessibility determinations than the geometric order prevailing throughout the interior of the crystallite.

Experimental

The following solvents (v/v) were used to separate the sugars and their derivatives : (*A*) butan-1-ol–benzene–pyridine–water (5 : 1 : 3 : 3; top layer), (*B*) butan-1-ol–ethanol–water (4 : 1 : 5; top layer), and (*C*) benzene–ethanol–water (169 : 49 : 15; top layer).

Preparation of Degraded Esparto Cellulose.—Esparto holocellulose was prepared from the grass as described by Chanda, Hirst, Jones, and Percival.[15] The holocellulose (100 g.) was extracted first with cold 4% sodium hydroxide solution (2 l.) for 24 hr. and then hot 6% sodium hydroxide solution (2 l.) for 24 hr. under a steam pressure of 40—45 lb. per sq. in., washed with water until free from alkali, and dried with ethanol to give esparto cellulose (70 g.).

Cellulose sols were prepared in a manner similar to that described by Rånby.[3] Esparto cellulose (30 g.) was heated at 100° with 10% sulphuric acid (300 c.c.) for 1—8 hr. The degraded cellulose was separated at the centrifuge and washed repeatedly with water (batches of 800 c.c.). Peptisation occurred at the 4th or 5th washing (pH 4—5) and continued until about the 10th washing. The cellulose sols were separated from fibrous material by centrifugation at 1500 r.p.m. and the colloidal cellulose was coagulated by the addition of sodium chloride (0·5 g. per l.). The light flocculent precipitate was separated at the centrifuge, washed twice with water (200 c.c.) to remove the electrolyte, and freeze-dried. The degraded cellulose was obtained in an average concentration of 2 g. per l. Chromatography of the hydrolysate (Monier-Williams) showed the presence of glucose and a trace of xylose.

Methylation of Degraded Esparto Cellulose.—Degraded esparto cellulose (11 g.) was methylated fifteen times with methyl sulphate and sodium hydroxide, rigorous precautions being used to exclude atmospheric oxygen.[5] The product was methylated twice more with methyl iodide and silver oxide, and the methylated cellulose was fractionated in hot chloroform–light petroleum (b. p. 60—65°) mixtures. Two main fractions, 1 (0·85 g.; OMe, 43·4%) and 2 (1·95 g.; OMe, 42·9%), were obtained and these were combined for subsequent work. Chromatography of a sample hydrolysate showed the presence of tetra-, tri-, and di-*O*-methylglucoses.

Hydrolysis of Methylated Cellulose and Separation of Methylated Sugars.—Methylated degraded esparto cellulose (2·6 g.) was heated with methanolic 3% hydrogen chloride (35 c.c.) in a sealed tube at 96° for 24 hr. and the resulting syrup was heated on the water-bath with 0·5N-hydrochloric acid (160 c.c.) for 16 hr. After neutralisation with silver carbonate and deionisation with Amberlite resins IR-100 and IR-4B, the solution was concentrated to a syrup (2·5 g.) which crystallised. The hydrolysate was fractionated on cellulose[16] (100 × 3 cm.) with light petroleum (b. p. 100—120°)–butan-1-ol (7 : 3), saturated with water, as eluant to give four fractions.

Fraction 1. The syrup (43 mg.) travelled on the chromatogram at the same rate as 2 : 3 : 4 : 6-tetra-*O*-methyl-D-glucose but hypoiodite oxidation indicated only 61% of aldose. After further hydrolysis of the syrup with 0·5N-hydrochloric acid (25 c.c.) on the water-bath for 8 hr., the product was separated on filter sheets to give fractions 1*a* (25 mg.) and 1*b* (10 mg.). Fraction 1*a* crystallised and had m. p. and mixed m. p. (with 2 : 3 : 4 : 6-tetra-*O*-methyl-D-glucose) 89—94° {$[\alpha]_D^{18}$ + 100° ⟶ + 80° (*c*, 0·09 in H_2O)}. The derived 2 : 3 : 4 : 6-tetra-*O*-methyl-*N*-phenyl-D-glucosylamine had m. p. and mixed m. p. 125—130°. Fraction 1*b* travelled on the chromatogram at the same rate as 2 : 3 : 6-tri-*O*-methyl-D-glucose and was not examined further. The corrected weight (29 mg.) of tetra-*O*-methyl-D-glucose corresponded to an average chain length of 77 ± 3 glucose residues.

Fraction 2. The chromatographically pure syrup (1·88 g.) crystallised readily and after recrystallisation from dry ether had m. p. and mixed m. p. (with authentic 2 : 3 : 6-tri-*O*-methyl-D-glucose) 108—113°, $[\alpha]_D^{18}$ + 85° ⟶ + 63° (*c*, 0·25 in H_2O), $[\alpha]_D^{18}$ + 70° ⟶ − 38° (*c*, 0·58 in methanolic 1% hydrogen chloride); OMe, 42·4%.

Fraction 3. The syrup (35 mg.) which did not crystallise had $[\alpha]_D^{18}$ + 95° ⟶ + 60° (*c*, 0·3 in H_2O) and travelled on the chromatogram at the same rate 2 : 3-di-*O*-methyl-D-glucose. Periodate oxidation[17] gave 0·86 mole of formaldehyde per mole of dimethyl sugar, estimated as the formaldehyde–dimedone compound.

Fraction 4. The syrup (194 mg.) which did not crystallise had $[\alpha]_D^{18}$ + 72° ⟶ + 55° (*c*, 0·15

[15] Chanda, Hirst, Jones, and Percival, *J.*, 1950, 1289.
[16] Hough, Jones, and Wadman, *J.*, 1949, 2511.
[17] Bell, *J.*, 1948, 992.

in H_2O) and $[\alpha]_D^{18}$ $+73° \longrightarrow -50°$ (c, 0·26 in methanolic 1% hydrogen chloride). The syrup was converted into the methyl glycosides, and the product was oxidised with sodium metaperiodate solution.[17] The consumption of periodate corresponded to the presence of 66% of 2 : 6-di-*O*-methyl-D-glucose in the fraction. After destruction of excess of periodate, the chloroform-soluble extract was hydrolysed and chromatography showed the presence of a single sugar corresponding to 3 : 6-di-*O*-methyl-D-glucose.

In addition to the major components described, chromatographic evidence was obtained for the presence of traces of 2 : 3 : 4-tri-*O*-methyl- and 2-*O*-methyl-xylose (R_G 0·97 and 0·05 in solvent *C*).

Periodate Oxidation of Degraded Esparto Cellulose.—Oxidation of the cellulose (100 mg. batches) with potassium metaperiodate solution by the method of Halsall, Hirst, and Jones [8] yielded a practically constant amount of formic acid after 49 hr., corresponding to 1 mole per 23—24 glucose residues. The production of 1 mol. of formic acid per non-reducing end-group and 2 mols. per reducing end-group being assumed, this value corresponds to an average chain length of 69—72. A sample of degraded cellulose, prepared in a similar manner from Whatman No. 1 filter paper, yielded, on periodate oxidation, formic acid corresponding to an average chain length of 91—94.

Determination of Chemical Accessibility by Nickerson's Method.—The apparatus used was essentially that described by Conrad and Scroggie,[18] in which the carbon dioxide evolved was determined gravimetrically in absorption tubes packed with " Sofnolite " absorbent (15 g.) and magnesium perchlorate (10 g.). To ensure greater uniformity in the conditions under which cellulose and glucose were subjected to the oxidative hydrolysis the two reaction flasks were heated in the same bath at 132° ± 0·5°, and equal flow-rates of the air currents passing through the parallel reaction vessels were maintained.

Cellulose samples (1·5 g.) were heated in a boiling ferric chloride–hydrochloric acid mixture (150 c.c.; 0·6M; 2·4N), the absorption tubes being weighed periodically. The carbon dioxide evolved from samples of glucose (1·3 g.) treated under the same conditions in the parallel reaction flask was determined concurrently.

By means of Nickerson's formula [6] the experimental results (shown in Fig. 1 as carbon dioxide–time data) were converted into percentage hydrolysis–time curves (Fig. 2), from which the accessibilities were obtained by extrapolation to zero time through the 2—4 hr. period.

Determination of Accessibility by Water Sorption Measurements.—Water-vapour sorption and desorption measurements were made with a simple type of McBain–Baker sorption balance.[19] Cellulose samples under investigation were placed in a glass bucket suspended from a glass spring (sensitivity 14·42 cm./g.). The sorption chamber was connected to a high-vacuum pump through a manometer and a drying-tube (magnesium perchlorate), and a bulb containing water as the source of vapour was directly connected to the sorption chamber.

Zero readings were taken after complete evacuation of the system and after the source of water vapour had been completely degassed. The cellulose sample (*ca.* 0·15 g.) was then placed in the bucket and the system was evacuated (*ca.* 36 hr.) until the cellulose was thoroughly dry (as indicated by minimum extension of the spring). Small quantities of water vapour were then admitted, and after equilibrium had been established, the vapour pressure was measured directly by the change in the manometer levels and the moisture regain was calculated from the extension of the spring. The process was repeated until the maximum equilibrium pressure was reached. Desorption measurements were made by following the changes in water-vapour pressure and moisture regain during the gradual evacuation of the system. A typical plot of sorption–desorption data is given in Fig. 4 where moisture regain is plotted against relative humidity. Calculations of the accessibilities of the cellulose samples were made by means of the theoretical isotherm of Hailwood and Horrobin.[9] The best curves were obtained from the experimental data by the application of the method of least squares and Fig. 4 shows the close agreement between observed and calculated values for moisture regain when plotted against relative humidity in the case of the degraded esparto cellulose.

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DEPARTMENT OF CHEMISTRY, UNIVERSITY OF EDINBURGH. [*Received, October 3rd,* 1955.]

[18] Conrad and Scroggie, *Ind. Eng. Chem.*, 1945, **37**, 592.
[19] McBain, " Sorption of Gases by Solids," London, 1932.

138. *The* Si–$C_{aromatic}$ *Bond in Polyphenylsilyl Compounds: The Acid Strengths of the Series of Acids* p-$Me_{4-n}Ph_{n-1}Si{\cdot}C_6H_4{\cdot}CO_2H$.*

By J. Chatt and A. A. Williams.

The acid dissociation constants of the above series of acids have been measured (Table 1) and it is shown that the *Si*-phenyl group is just slightly more electron attracting than the *Si*-methyl group in this series. There is no marked discontinuity in the series of acid strengths, indicating that the sum of the opposing mesomeric ($+M$) and inductive effects ($-I$) of the *Si*-phenyl group changes very slightly and continuously as *Si*-methyl groups are replaced by *Si*-phenyl groups. The mesomeric effect might have been expected to show a discontinuity after more than two phenyl groups had been attached to the silicon atom.

We have shown that in the anion p-$Me_3Si{\cdot}C_6H_4{\cdot}CO_2^-$, d_π-p_π-bonding occurs between the silicon atom and the aromatic carbon atom.[1] The electrons in this π-type bond are provided from the π-molecular-orbital system of the aromatic nucleus, and the strength of the acid is a sensitive indication of the electron-attracting or -releasing properties of the silyl group.

The replacement of one of the methyl groups by a phenyl group introduces two opposing electronic effects which would influence the acid strength. The more electronegative phenyl group, by increasing the electron withdrawal in the σ-bond ($-I$), should enhance the acid strength. On the other hand, electron release from the phenyl group into a *d*-orbital of the silicon atom ($+M$) in d_π-p_π-bond formation should reduce the acid strength. It was of interest to see which of these effects predominates and whether the predominance of one over the other depends on the number of aromatic nuclei attached to the silicon atom. Kimball[2] has predicted that a tetrahedrally co-ordinated atom (sp^3) such as silicon can form a maximum of two strong and three weak π-bonds. We might expect therefore that the average mesomeric effect of the phenyl group would stay roughly constant until two aromatic nuclei were attached to the silicon atom, then fall rapidly as more phenyl groups were introduced. We have therefore prepared the series of phenylsilylbenzoic acids p-$Me_{4-n}Ph_{n-1}Si{\cdot}C_6H_4{\cdot}CO_2H$ (see footnote) and measured their acid strengths.

The acids were prepared by carboxylation of the Grignard reagent derived from the halides, p-$Me_{4-n}Ph_{n-1}Si{\cdot}C_6H_4Br$, which were obtained by the following series of reactions:

(1) $Me_2PhSiCl + p\text{-}BrMg{\cdot}C_6H_4Br \longrightarrow p\text{-}Me_2PhSi{\cdot}C_6H_4Br$

(2) $MeSiCl_3 + p\text{-}BrMg{\cdot}C_6H_4Br \longrightarrow p\text{-}Br{\cdot}C_6H_4{\cdot}SiMeCl_2 \xrightarrow{2PhMgBr} p\text{-}MePh_2Si{\cdot}C_6H_4Br$

(3) $SiCl_4 + p\text{-}BrMg{\cdot}C_6H_4Br \longrightarrow p\text{-}Br{\cdot}C_6H_4{\cdot}SiCl_3 \xrightarrow{3PhMgBr} p\text{-}Ph_3Si{\cdot}C_6H_4Br$

The acid strengths were measured as previously described [1] and are recorded in Table 1.

Table 1. *The thermodynamic dissociation constants* (K_a) *of* p-$Me_{4-n}Ph_{n-1}Si{\cdot}C_6H_4{\cdot}CO_2H$ *in 60·1% (by weight) aqueous ethanol at 25°.*

n	1	2	3	4
10^6K_a	1·11 *	1·28	1·51	1·81

* Taken from ref. 1 for comparison.

The acid strengths increase slightly with the number of phenyl groups, n, and so phenyl groups attached to silicon tend, on balance, to be only slightly more electron-attracting than methyl groups, *i.e.*, the influence of their inductive effects ($-I$) slightly outweighs that of their mesomeric effects ($+M$).

The observed increase in acid strength is continuous throughout the series from $n = 1$

* n = Total number of aromatic nuclei attached to the silicon atom.

[1] Chatt and Williams, *J.*, **1954**, 4403.
[2] Kimball, *J. Chem. Phys.*, **1940**, **8**, 188.

to $n = 4$. The discontinuity expected between $n = 2$ and $n = 3$ does not occur. There is the possibility of a discontinuity between $n = 1$ and $n = 2$. We cannot investigate this by using our series of acids, but the series of acids $Me_nPh_{3-n}Si{\cdot}CH_2{\cdot}CO_2H$ would be a suitable one in which to investigate that possibility. The strengths of two members have been recorded.[3] $Me_3Si{\cdot}CH_2{\cdot}CO_2H$ has $10^5K_a = 0{\cdot}60$ and $Me_2PhSi{\cdot}CH_2{\cdot}CO_2H$ has $10^5K_a = 0{\cdot}54$ in water at 25°. Here a slight decrease in acid strength has occurred on replacing the methyl group, suggesting that the first phenyl group to be introduced in place of a methyl group is, on balance, more electron-releasing than the methyl group. It is interesting to compare this small change in acid strength with the larger change, of opposite sign, produced in comparable carbon systems where only the inductive effects of the phenyl group can operate, *e.g.*, $Me{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$ has [4] $10^5K_a = 1{\cdot}50$, but $Ph{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$ has [5] $10^5K_a = 2{\cdot}19$.

It is evident that the replacement of an *Si*-methyl group by an *Si*-phenyl group has little effect on the electron-attracting or -releasing properties of the silyl group containing them. The negative inductive effect of the phenyl group is about balanced by its positive mesomeric effect. In the series of acids which we have studied there is never less than one benzene nucleus attached to the silicon atom. In these circumstances, on replacement of a methyl group by a phenyl group, the change in inductive effect ($-I$) just outweighs the change in mesomeric effect ($+M$).

This finding besides its interest for its own sake is of interest in co-ordination chemistry. When the tertiary organic derivatives of phosphorus, arsenic, and antimony are co-ordinated to a transition metal, the Group V element is in a similar state to silicon in the above series of silylbenzoic acids. For example, in the compound $[(PR_3)_2PtCl_2]$ the phosphorus is tetrahedrally co-ordinated and takes part in π-type bonding to the platinum atom. The platinum atom supplies the electrons from its *d*-orbitals as the aromatic system does from its π-molecular orbitals. If the phenyl groups in these complex compounds are also, on balance, electron-withdrawing as compared with alkyl groups, the tertiary aromatic phosphines, arsines, and stibines should be poorer donors than the aliphatic. Therefore, in the inner orbital complexes of metals, towards the ends of the transition series, with tertiary, organic phosphines, arsines, and stibines the σ-bond, which is a donor bond, should be weakened, and the π-type bond, which is an acceptor bond, should be strengthened when alkyl are replaced by aryl groups. The aromatic phosphines, etc., should therefore be more strongly double bonding to the metal than their aliphatic analogues. There is some experimental evidence in support of this. Increased double bonding by the atom, M (M = P, As, or Sb), should stabilise the *cis*-relative to the *trans*-isomer in complexes of the type $[(MR_3)_2PtCl_2]$.[6] It is interesting that only the *cis*-isomer of $[(PPh_3)_2PtCl_2]$ is known,[7] but that fact is not proof that the *trans*-isomer is unstable. More definite evidence of the influence of the phenyl group is provided by the equilibrium [8] between *cis*- and *trans*-$[(AsBu^n_2Ph)_2PtCl_2]$. It lies much further to the *cis*-side ($K = 9{\cdot}6$) than does the equilibrium between the isomeric forms of $[(AsBu^n_3)_2PtCl_2]$ ($K = 340$), as would be expected if the presence of the phenyl group increases the double-bond character of the As–Pt bond.

Experimental

Microanalyses are by Messrs. W. Brown and A. G. Olney of these laboratories.

Preparation of Acids.—p-*Bromophenyldimethylphenylsilane.* Chlorodimethylphenylsilane (76 g., 1 mol.) in ether (100 c.c.) was added to the Grignard reagent prepared from *p*-dibromobenzene (208 g., 2 mol.) in ether (700 c.c.) and magnesium (21·2 g., 2 mol.) in ether (50 c.c.). The mixture was boiled under reflux for 18 hr. and then hydrolysed. The ethereal layer was washed

[3] Sommer, Gold, Goldberg, and Marans, *J. Amer. Chem. Soc.*, 1949, **71**, 1509.
[4] Dippy, *J.*, 1938, 1222.
[5] Dippy and Lewis, *J.*, 1937, 1008.
[6] Chatt and Williams, *J.*, 1951, 3061; Craig *et al.*, *J.*, 1954, 332; Jaffé, *J. Phys. Chem.*, 1954, **58**, 185.
[7] Jensen, *Z. anorg. Chem.*, 1936, **229**, 242.
[8] Chatt and Wilkins, *J.*, 1956, 525.

with water and dried (Na_2SO_4), then fractionated, and the fraction (60 c.c.) of b. p. 153—205°/12 mm. collected. It was purified further by fractionation up a column packed with Dixon rings, and the fraction of b. p. 187—188°/16 mm. collected. This silane (15·5 g.) was sufficiently pure for the next stage in the synthesis (Found : C, 58·7; H, 5·5. Calc. for $C_{14}H_{15}BrSi$: C, 57·7; H, 5·2%).

p-(*Dimethylphenylsilyl*)*benzoic acid*. The above silane (15·5 g., 1 mol.) in ether (175 c.c.) was added with stirring to magnesium (38·5 g., 30 mol.) covered with ether (100 c.c.). During the addition (2 hr.) the magnesium suspension was very vigorously stirred and kept at the boil by external heating. This was continued for a further 2½ hr., then the Grignard reagent, so prepared, was poured on solid carbon dioxide and set aside overnight. The product was hydrolysed with dilute hydrochloric acid, and the ether layer extracted with sodium carbonate solution. Dissolved ether was removed from this solution by warming it, and then, after it had cooled, it was acidified to precipitate the crude acid (10 g.). Recrystallised once from aqueous ethanol, four times from light petroleum, and twice from ethanol, the *acid* was obtained in white crystals (2 g.), m. p. 110—111° (Found : C, 70·2; H, 6·35%; equiv., 258. $C_{15}H_{16}O_2Si$ requires C, 70·3; H, 6·3%; equiv., 256·3).

p-*Bromophenylmethyldichlorosilane*. The Grignard reagent from *p*-dibromobenzene (236 g., 1 mol.) in ether (1000 c.c.) was added slowly (2 hr.) with stirring to methyltrichlorosilane (150 g., 1 mol.). Throughout the addition the mixture was kept at such a temperature that the ether boiled under reflux and the boiling was continued for a further 4½ hr. after the addition. The resultant ethereal reaction mixture was not hydrolysed but was filtered under dry conditions, and the residue extracted with ether. The ethereal extract and filtrate were combined and fractionated. The fraction, b. p. 115—130°/11 mm., was collected (70 g.) and used without further purification or characterisation in the following preparation.

p-*Bromophenylmethyldiphenylsilane*. The above product (70 g., *ca.* 1 mol.) in benzene (100 c.c.) was added to the Grignard reagent obtained from bromobenzene (155 g., 4 mol.) and magnesium (24 g., 4 mol.) in ether (400 c.c.), and the mixture boiled under reflux for 7 hr. After 14 hr. at room temperature, the product was hydrolysed with ammonium chloride solution, and the ether layer removed. This was washed, dried, and distilled. The fraction, b. p. 180—220°/0·5 mm., solidified and after four recrystallisations from ethanol gave the pure *silane*, m. p. 102—103° (8·1 g.) (Found : C, 64·6; H, 4·7. $C_{19}H_{17}BrSi$ requires C, 64·6; H, 4·85%).

p-(*Methyldiphenylsilyl*)*benzoic acid* was prepared from the above silane (8·1 g.) in the same way as its dimethylphenyl analogue (above). The crude *acid* (6 g.) was recrystallised twice from ethanol to give 2·8 g. of pure material, m. p. 200—201·5° (Found : C, 75·45; H, 5·9%; equiv., 320. $C_{20}H_{18}O_2Si$ requires C, 75·4; H, 5·7%; equiv., 318).

p-*Bromophenyltriphenylsilane*. *p*-Bromophenyltrichlorosilane [9] (74·3 g., 1 mol.) was added in toluene (200 c.c.) to the Grignard reagent prepared from bromobenzene (180 g., 4·5 mol.) and magnesium (27·5 g., 4·5 mol.) in ether (600 c.c.). The ether was then distilled away, a further 350 c.c. of toluene were added, and the mixture was boiled under reflux for 16 hr. The product was hydrolysed by dilute hydrochloric acid, and the organic layer removed, dried, and distilled until about 150 c.c. of liquid residue remained. The addition of ethanol (500 c.c.) caused separation of the crude silane (50 g.), m. p. 160—174°. Seven recrystallisations from benzene–ethanol did not yield a pure product (Found : C, 71·3; H, 4·6. Calc. for $C_{24}H_{19}BrSi$: C, 69·4; H, 4·6%). This material was converted into the acid.

p-(*Triphenylsilyl*)*benzoic acid*. The Grignard reagent derived from the preceding silane was prepared by the " entrainment method." The silane (5·6 g.) and ethyl bromide (5·7 g.) in ether (50 c.c.) were slowly added with stirring to magnesium (2·5 g.) in ether (10 c.c.), and the mixture boiled under reflux for 1 hr. after the addition. The mixture was then poured on solid carbon dioxide, kept overnight, and hydrolysed with dilute hydrochloric acid, and the organic product extracted with benzene. The benzene solution was evaporated to a small volume and shaken with sodium carbonate solution. The precipitate of the sodium salt which was formed was filtered off and suspended in water. This suspension was made acid with hydrochloric acid and filtered, and the solid residue recrystallised from benzene–light petroleum. One further recrystallisation gave the pure white *acid*, m. p. 217—218·5° (1 g.) (Found : C, 78·3; H, 5·5%; equiv., 381. $C_{25}H_{20}O_2Si$ requires C, 78·3; H, 5·3%; equiv., 380·5).

Dissociation Constants.—These were determined by the method and under the conditions used for the trimethylsilylbenzoic acid.[1] The results are listed in Table 2 corresponding to Table 3 of the previous publication.[1]

[9] Grüttner and Krause, *Ber.*, 1917, **50**, 1559.

TABLE 2. *Experimental quantities determined to measure the thermodynamic acid dissociation constants, K, in 60·1% ethanol (by wt.) at 25°.*

10^3I	10^3C_A	10^4P	$10^6K'$	10^6K	10^3I	10^3C_A	10^4P	$10^6K'$	10^6K
				p-$Me_2PhSi{\cdot}C_6H_4{\cdot}CO_2H$.					
3·080	0·4584	4·048	1·754	1·278	3·011	0·5304	4·357	1·751	1·280
3·344	0·4543	4·021	1·746	1·255	2·536	0·6368	4·673	1·670	1·253
2·767	0·5352	4·376	1·751	1·297	2·938	0·6256	4·803	1·782	1·308
			$K = 1·279 \times 10^{-6}$; standard deviation ±0·022.						
				p-$MePh_2Si{\cdot}C_6H_4{\cdot}CO_2H$.					
2·689	0·1833	2·694	1·999	1·487	3·125	0·1244	2·257	2·103	1·528
2·865	0·1816	2·742	2·094	1·543	3·149	0·1333	2·306	2·041	1·481
2·878	0·1256	2·221	2·014	1·483	3·284	0·1326	2·345	2·126	1·532
3·014	0·1250	2·249	2·077	1·518					
			$K = 1·510 \times 10^{-6}$; standard deviation ±0·024.						
				p-$Ph_3Si{\cdot}C_6H_4{\cdot}CO_2H$.					
2·307	0·202	3·098	2·406	1·830	2·651	0·200	3·086	2·408	1·795
2·444	0·201	3·088	2·404	1·813	2·858	0·200	3·102	2·438	1·797
2·515	0·201	3·088	2·400	1·803					
			$K = 1·808 \times 10^{-6}$; standard deviation ±0·014.						

I = Ionic strength of solution; C_A = concentration of weak acid; K' = concentration dissociation constant; K = thermodynamic dissociation constant; P = an experimentally determined quantity calculated as described in ref. 1.

The authors thank Imperial Chemical Industries Limited, Nobel Division, for gifts of dimethylphenylchlorosilane and methyltrichlorosilane, and Mr. G. Barton for assistance with some of the preparations.

AKERS RESEARCH LABORATORIES, IMPERIAL CHEMICAL INDUSTRIES LIMITED,
THE FRYTHE, WELWYN, HERTS. [*Received, October 4th*, 1955.]

139. *Compounds of Potential Pharmacological Interest. Part I. Acyl Derivatives of 1-Amino-3-phenylindane.*

By P. G. PHILPOTT and J. A. BARLTROP.

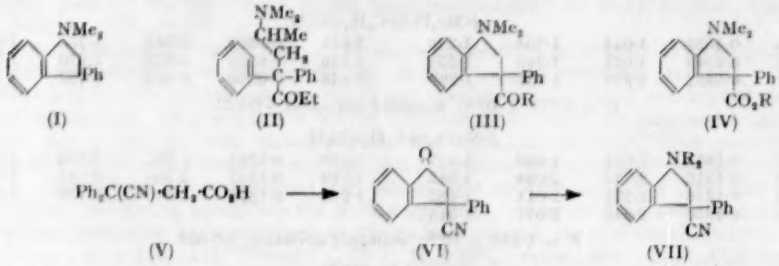
As part of a search for new analgesics, 1-cyano-3-dimethylamino-1-phenylindane (VII; R = Me) has been synthesised (i) by cyclising β-cyano-ββ-diphenylpropionic acid to the indanone and then reducing and alkylating the oxime, and (ii) by brominating and aminating 1-cyano-1-phenylindane (X). Two isomeric forms of the amine (VII; R = Me) were obtained from (X) depending on the techniques adopted for its synthesis and bromination. Only one of these isomers could be converted into 3-dimethylamino-1-ethoxycarbonyl-1-phenylindane. Unsuccessful attempts to prepare 1-acyl-3-dimethylamino-1-phenylindanes, which are cyclic analogues of amidone, are described. Ethyl-lithium reacts with 1-cyano-3-dimethylamino-1-phenylindane, and ethylmagnesium iodide reacts with the oxime of 1-cyano-1-phenyl-3-indanone by replacing the nitrile group with hydrogen.

IN Part IV [1] the synthesis and pharmacological properties of alkyl derivatives of 3-phenyl-1-indanylamines will be described, and attention will be drawn to the marked analgesic properties of 1-dimethylamino-3-phenylindane (I). Because of the superficial resemblance between the 3-phenylindane (I) and amidone (II), it became important to prepare the ketones (III), which are cyclic members of the amidone series and the esters (IV; R = Et), which are related cyclically to Bockmühl and Ehrhart's amino-esters.[2a]

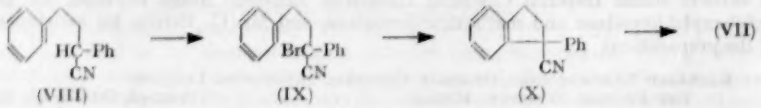
The synthesis of these compounds was first attempted through the reaction sequence (V) ⟶ (VII). β-Cyano-ββ-diphenylpropionic acid (V) was readily obtained by alkylating

[1] Acheson, Philpott, MacPhee, Hunt, and Barltrop, to be published.
[2] (*a*) Bockmühl and Ehrhart, G.P. 711,069; *Chem. Abs.*, 1943, **37**, 4075. (*b*) *Idem*, *Annalen*, 1949, **561**, 71; May and Mosettig, *J. Org. Chem.*, 1948, **13**, 459.

diphenylacetonitrile with ethyl bromoacetate and sodamide in liquid ammonia and hydrolysing the product. Under precisely defined conditions, the corresponding acid chloride could be cyclised in excellent yields to 3-cyano-3-phenylindan-1-one (VI), the



oxime of which was reduced with sodium amalgam to 3-amino-1-cyano-1-phenylindane (VII; R = H) in 55% yield. Catalytic hydrogenation of the oxime and the Leuckart reaction provided unsatisfactory methods of transforming the ketone (VI) into the base (VII; R = H). Methylation of the primary base (VII; R = H) with formic acid and formaldehyde gave poor yields of the tertiary amine, and at this point an alternative synthesis of 1-cyano-3-dimethylamino-1-phenylindane became available through the reactions (VIII) ⟶ (X) ⟶ (VII).



Phenylacetonitrile was smoothly alkylated with phenethyl bromide by means of sodamide in liquid ammonia. The resulting 2 : 4-diphenylbutyronitrile (VIII) was brominated and the crude 2-bromo-2 : 4-diphenylbutyronitrile (IX) was cyclised under a variety of conditions to give 1-cyano-1-phenylindane (X), which was brominated and treated with dimethylamine to give the base (VII; R = Me); but three apparently different bases were obtained according to the method of preparing and brominating the indane (X). The use of aluminium chloride as a catalyst for cyclisation of the bromide (IX) was investigated closely and optimum conditions were defined under which it was possible to obtain the product (X) in 49% yield from (VIII). The product (X) from this reaction was designated indane-A. Ferric chloride appeared to be almost as effective as aluminium chloride and gave a 44% yield of indane-B, but stannic chloride at 80° gave a 75% yield of indane-C. The indanes-A, -B, and -C were brominated smoothly in carbon tetrachloride and the resulting bromo-compounds were converted, without purification, into the bases (VII; R = Me). From indane-A was obtained 1-cyano-3-dimethylamino-1-phenylindane hydrochloride (β), so called because it was different from the α-compound obtained earlier from the ketone (VI). The β-compound persistently melted over a range in spite of repeated crystallisation. The product from indane-B was a mixture of the β-compound and a higher-melting, more insoluble hydrochloride [1-cyano-3-dimethylamino-1-phenylindane hydrochloride (γ)]. The product from indane-C was exclusively the γ-compound, which was also obtained from indane-A if the bromination was catalysed by a trace of benzoyl peroxide. An analysis of the m. p.s and mixed m. p.s of the hydrochlorides and picrates of the bases (see Experimental section) showed that there were in fact only two distinct isomers, the α- and the γ-compound, and that the β-compound is an impure form of the α-compound probably contaminated with a little of the less soluble γ-compound which could not readily be removed by recrystallisation. The α-compound must be an indane because of its preparation from the indanone (VI), and the γ-compound must also be cyclic and therefore an indane from the fact that it resists catalytic hydrogenation. Thus there can be little doubt but that the α- and the γ-compound are *cis–trans*-isomers of 1-cyano-3-dimethylamino-1-phenylindane (VII; R = Me) and the question arises how different

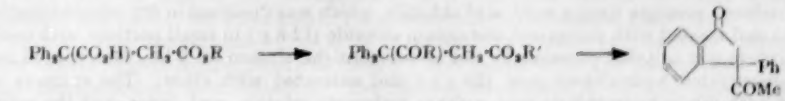
specimens of (X), which can exist in only one form, can give rise to *cis–trans*-isomers of (VII; R = Me) when brominated and aminated under apparently identical conditions.

The simplest explanation is in terms of the remarkable fact mentioned above, that indane-A prepared from the aluminium chloride cyclisation gives rise to the α- or γ-isomer depending on whether the bromination is effected in the presence or absence of benzoyl peroxide. If the cyclisation catalysed by the weaker catalyst stannic chloride be postulated to be incomplete, giving the indane-C (X) contaminated by traces of olefins, which autoxidise to peroxides which behave similarly to benzoyl peroxide in influencing the stereochemical course of the bromination reaction, then we have an explanation of the differing behaviour of indanes-A and -C. One must further postulate that in the case of indane-B, prepared through the agency of ferric chloride, so little peroxide was formed that the normal and the peroxide-catalysed reaction occurred at comparable rates.

As would be expected from the sterically hindered position of the nitrile group, esterification of the α-base (VII; R = Me) was successful only under forcing conditions. In addition to the ester (IV; R = Et) a small quantity of the acid (IV; R = H) was isolated. A similar reaction with the γ-isomer gave no ester but mainly starting material together with a small quantity of the amide.

Several unsuccessful attempts were made to prepare ketones of the type (III). Although diphenylmethane may be metalated at the methylene group, our efforts to prepare the corresponding 3-lithio-derivative of the indane (I) with butyl-lithium and then to condense it with propionyl chloride led only to recovery of starting material. Since reaction with butyl-lithium followed by carboxylation gave none of the amino-acid (IV; R = H), it is clear that no metalation occurred under these conditions. The next attempts proceeded from the reaction between the amino-nitrile (VII; R = Me) and organometallic compounds. With Grignard reagents either starting material or non-basic degradation products were obtained depending on the reaction temperature, but with ethyl-lithium a base was obtained in which it appeared that the cyano-group had been removed, giving an indanylamine (I), different from the specimen described in Part IV,[1] and to which it is presumably related by *cis–trans*-isomerism. The replacement of a nitrile group by hydrogen is not new, and a similar degradation of amino-nitriles in which the cyano-group is linked to a quaternary carbon atom has been reported previously,[2b] but only in the presence of sodamide and potassium hydroxide. Since the completion of this work, two instances have been reported of loss of a nitrile group occurring in the presence of Grignard reagents. The first is conversion of 4 : 5-bis(dimethylamino)-2 : 2-diphenylvaleronitrile by ethylmagnesium iodide at 100° into 3 : 4-bis(dimethylamino)-1 : 1-diphenylbutane instead of the expected ketone,[3] and the second a similar reaction at 120° with 9-cyano-9-2′-dimethylaminoethylfluorene.[4] Both these compounds are closely related to the substance (VII; R = Me) used in the present instance and the conditions closely parallel those prevailing in a similar reaction with the oxime of the cyano-ketone (VI) described below.

Because of these anomalies in the final stage of the preparation of the ketone (III), it became necessary to devise a synthesis in which the acyl group was introduced before ring-closure to the indane. The reaction sequence (XI) ⟶ (XIII) appeared promising.



(XI) (XII) (XIII)

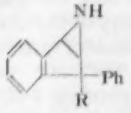
αα-Diphenylsuccinic acid was prepared by the hydrolysis of the cyano-acid (V) and esterified to give a mixture of the monoester (XI; R = Et) and the diester.[5] Thionyl chloride gave the acid chloride (XII; R = Cl, R′ = Et) which on reaction with dimethylcadmium gave the required ethyl γ-oxo-ββ-diphenylvalerate (XII; R = Me, R′ = Et) together with an acid $C_{18}H_{20}O_3$ which appears to be the *iso*alkanoic acid (XIV) formed by

[3] Schultz, *J. Amer. Chem. Soc.*, 1952, **74**, 5793.
[4] King, Meltzer, and Doczi, Abs. Papers 123rd Meeting Amer. Chem. Soc., 1953, 15L.
[5] Salmon-Legagneur, *Compt. rend.*, 1939, **208**, 1507.

the attack of dimethylcadmium on the less hindered carbonyl group of αα-diphenylsuccinic anhydride which results from the action of heat on the acid chloride. A second route to the ketone (XII; R = Me) lay through the diazo-ketone (XII; R = CHN_2), which was obtained by reaction between the acid chloride and diazomethane and on reduction with hydriodic acid gave a hydrated form of the keto-ester (XII; R = Me, R′ = Et). The keto-group of this ester was sterically hindered, and no dinitrophenylhydrazone was obtained. It therefore follows that the acid chloride from which it was derived must have the structure (XII; R = Cl, R′ = Et) and not the alternative (XII; R = OEt, and COCl instead of CO_2R') although Chase and Hey [6] have shown that the methyl ester (XI; R = Me) rearranged in thionyl chloride and gave the alternative acid chloride. All attempts to form the diketone (XIII) from the keto-acid (XII; R = Me, R′ = H) and its derivatives gave only traces of ketonic material.

The final work in this series involved the reaction of ethylmagnesium iodide with the oxime of the cyano-ketone (VI), which from the results of Campbell *et al.*[7] was expected to give the imine (XV; R = CN or $CEt{:}NH$) and thence a series of phenyl-1- and -2-indanyl-

(XIV) $Ph_2C(CO_2H)\cdot CH_2\cdot CMe_2\cdot OH$



(XV)

amines. The product obtained, however, was the base (XV; R = H), the nitrile group having been lost (see above).

A pharmacological examination of 3-dimethylamino-1-ethoxycarbonyl-1-phenylindane hydrochloride (IV; R = Et) was undertaken through the courtesy of Dr. G. E. Ullyot by Smith, Kline and French Laboratories, Philadelphia, U.S.A. The salt failed to show analgesic activity in rats after intraperitoneal injection (d'Amour-Smith method) at dose levels of 20—50 mg./kg. It produced stimulation in all animals at 50 mg./kg.

Experimental

β-Cyano-ββ-diphenylpropionic Acid.—Sodium (3·45 g.) was dissolved in liquid ammonia in the presence of a trace of ferric nitrate. When the blue colour had been discharged, a dry ethereal solution of diphenylacetonitrile [8] (29·1 g.) was added. The intensely yellow solution was cooled in acetone–solid carbon dioxide and treated with ethyl bromoacetate (25·5 g.), dropwise and with agitation. A vigorous reaction occurred with discharge of the colour. Evaporation of the solvents gave a partly crystalline material which was hydrolysed by boiling ethanolic potassium hydroxide for ½ hr. When cold, the precipitated solid was collected, dissolved in water, and acidified. β-Cyano-ββ-diphenylpropionic acid (23 g.) was collected and dried. Concentration of the alcoholic filtrate, dilution with water, and acidification yielded more acid (4 g.). On crystallisation from ethanol, the acid formed plates, m. p. 178° (Found : C, 76·6; H, 5·2. Calc. for $C_{16}H_{13}O_2N$: C, 76·5; H, 5·2%).

3-Cyano-3-phenylindan-1-one.—β-Cyano-ββ-diphenylpropionic acid (12·0 g.) and thionyl chloride (16 c.c.) were heated together under reflux for 1½ hr. Distillation of the thionyl chloride under reduced pressure gave a solid acid chloride, which was dissolved in dry tetrachloroethane (40 c.c.) and treated with pulverised aluminium chloride (12·8 g.) in small portions with cooling. The mixture was agitated occasionally, set aside overnight, shaken for 3 hr., then poured on ice and concentrated hydrochloric acid (25 c.c.) and extracted with ether. The extracts were washed with dilute hydrochloric acid, sodium carbonate solution, and water, and the solvents were removed by steam-distillation. The residual yellowish gum was isolated with ether and distilled. *3-Cyano-3-phenylindan-1-one* (8·7 g., 79·4%) was collected at 150—155°/0·1 mm. A specimen, crystallised from ethanol, gave colourless rhombs, m. p. 81° (Found : C, 82·3; H, 4·75; N, 6·2. $C_{16}H_{11}ON$ requires C, 82·3; H, 4·75; N, 6·0%).

1-Cyano-3-hydroxyimino-1-phenylindane.—The above ketone (8·7 g.) was boiled under reflux in aqueous ethanol with hydroxylamine hydrochloride (6·0 g.) and sodium acetate

[6] Chase and Hey, *J.*, 1952, 553.
[7] Campbell *et al.*, *J. Org. Chem.*, 1943, **8**, 103; 1944, **9**, 184.
[8] Ginsburg and Baiser, *J. Amer. Chem. Soc.*, 1949, **71**, 2254.

(15·0 g.) for 2 hr. The solution was cooled and poured into water (1 l.). *1-Cyano-3-hydroxyimino-1-phenylindane* slowly solidified; it crystallised from aqueous ethanol (very slow cooling) as needles (8·5 g., 92%), m. p. 176·5° (Found: C, 77·2; H, 4·9; N, 7·0. $C_{16}H_{12}ON_2$ requires C, 77·4; H, 4·9; N, 7·1%).

3-Amino-1-cyano-1-phenylindane.—(*a*) A solution of the above oxime (1·0 g.) in methanol (50 c.c.), acidified with 20% acetic acid (4 c.c.), was stirred vigorously and reduced with 3½% sodium amalgam (50 g.), added in portions during 1 hr., the solution being kept acid by the dropwise addition of 20% acetic acid. The solution, separated from mercury, was further acidified with hydrochloric acid and evaporated to small bulk under reduced pressure. Water was added, and the solution washed with ether, basified, and extracted with ether. The dried extracts, on treatment with dry ethereal hydrogen chloride, yielded a precipitate of 3-amino-1-cyano-1-phenylindane hydrochloride (0·6 g., 55%), which was collected and dried *in vacuo* over sodium hydroxide. The hydrochloride was converted into a *picrate* which crystallised from ethanol in needles, m. p. 220° (decomp.) (Found: C, 57·2; H, 3·55; N, 15·0. $C_{16}H_{14}N_2.C_6H_3O_7N_3$ requires C, 57·0; H, 3·7; N, 15·1%).

(*b*) A solution of the oxime (1·0 g.) in ethanol saturated with ammonia was hydrogenated at 100 atm. and room temperature in the presence of Raney nickel (0·5 g.). Working up in the usual way gave the amine hydrochloride (1·0 g., 91·5%) which was converted into a picrate identical with described above. This result was not reproducible, and, in general, only partial reduction was effected. Hydrogenation over Adams catalyst in ethanol containing hydrochloric acid gave only microscopic yields.

A Leuckart reaction conducted with 3-cyano-3-phenylindan-1-one (1·3 g.), ammonium formate (1·74 g.), and formic acid (2 c.c.) at 150° for 4 hr. gave, after hydrolysis of the substituted formamide, only 50 mg. of the picrate of the required amine. Starting material (0·8 g.) was recovered.

2 : 4-Diphenylbutyronitrile.—Sodium (6 g.) was dissolved in liquid ammonia in the presence of a trace of ferric nitrate. When the blue colour had disappeared, benzyl cyanide (30 g.) was added, the solution being cooled in acetone–solid carbon dioxide to modify the otherwise vigorous reaction. To this cooled, deep red solution, an ether solution of phenethyl bromide (48·2 g.) was added dropwise with stirring. The red colour was not discharged. Water was added to the semisolid residue after the evaporation of the ammonia, and the whole extracted with ether. The residue from the dried extracts was distilled *in vacuo* and *2 : 4-diphenylbutyronitrile* (36·8 g., 65·3%) collected at 132°/0·16 mm. (Found: C, 86·8; H, 7·2; N, 5·4. $C_{16}H_{15}N$ requires C, 86·9; H, 6·8; N, 6·3%). The highest yield obtained by this method was 71·4%. A lower yield (43%) was obtained when the benzyl cyanide and phenethyl bromide were mixed and then added to the sodamide in liquid ammonia.

1-Cyano-1-phenylindane.—(*a*) A solution of bromine (14·6 g.) in dry tetrachloroethane was added to one of 2 : 4-diphenylbutyronitrile (19·7 g.) in the same solvent. After 1½ hr. at 80°, bromination was complete, giving a straw-coloured solution of 2-bromo-2 : 4-diphenylbutyronitrile, which was immediately cyclised, by treatment at 0° with pulverised aluminium chloride (13 g.) in portions with agitation. The mixture was kept at 0° for 1 hr., with occasional agitation, then allowed to come to room temperature and kept for 40 hr. The mixture was poured on ice and concentrated hydrochloric acid (26 c.c.), and the layers were separated. The aqueous layer was extracted with benzene and the combined organic solutions were dried and distilled. *1-Cyano-1-phenylindane* (9·7 g., 49%) was collected at 122°/0·2 mm. (Found: C, 87·7; H, 6·3; N, 6·0. $C_{16}H_{13}N$ requires C, 87·7; H, 5·9; N, 6·4%). This specimen is designated indane-A. All variations of the above conditions caused a lower yield.

(*b*) The tetrachloroethane solution of 2-bromo-2 : 4-diphenylbutyronitrile, prepared as above from 2 : 4-diphenylbutyronitrile (8·05 g.), was cooled to 0° and treated with anhydrous ferric chloride (6·5 g.), with agitation. The mixture was kept at 0° for 1 hr. and then allowed to remain at room temperature overnight. The product, worked up as above, gave 1-cyano-1-phenylindane-B (3·5 g., 43·5%), apparently identical with the indane-A described above.

(*c*) 2-Bromo-2 : 4-diphenylbutyronitrile in tetrachloroethane was kept for 3 hr. at 80° with stannic chloride (1 mol.), then overnight at room temperature. Working up gave 1-cyano-1-phenylindane-C (6·05 g., 75·3%), apparently identical with the specimens described above.

1-Cyano-3-dimethylamino-1-phenylindane.—(*a*) 3-Amino-1-cyano-1-phenylindane (1·2 g.), formic acid (5 c.c.), and 40% aqueous formaldehyde (1 c.c.) were heated together on the steam-bath. When the vigorous evolution of carbon dioxide had abated, the solution was boiled for 5 min. under reflux, cooled, basified with potassium hydroxide, and extracted with ether. The residue from the dried extracts was dissolved in dilute hydrochloric acid and treated at 0° with

aqueous sodium nitrite. The resulting solution was washed with ether, basified, and extracted with ether. The dried extracts were treated with dry ethereal hydrogen chloride, and 1-*cyano*-3-*dimethylamino*-1-*phenylindane hydrochloride* (α) precipitated as an orange gum. After drying *in vacuo* over sodium hydroxide it crystallised from *tert.*-butyl alcohol in colourless needles, m. p. 215—217° (Found: C, 70·3; H, 6·55; N, 8·9. $C_{18}H_{18}N_2,HCl,\frac{1}{2}H_2O$ requires C, 70·2; H, 6·5; N, 9·1%). The *picrate*, recrystallised from ethanol, had m. p. 223° (decomp.) (Found: C, 58·9; H, 4·5; N, 14·1. $C_{18}H_{18}N_2,C_6H_3O_7N_3$ requires C, 58·6; H, 4·3; N, 14·3%).

(*b*) 1-Cyano-1-phenylindane-A (8·5 g.) and bromine (1·95 c.c.) were heated under reflux in carbon tetrachloride until reaction was complete (4—6 hr.). Evaporation under reduced pressure gave crude 3-bromo-1-cyano-1-phenylindane. This compound (5·5 g.), dissolved in dry dioxan, was cooled to −15° and treated with similarly cooled dimethylamine (2·5 g.). The mixture was allowed to react at room temperature for 1 week in a sealed pressure-bottle. The solution was filtered from the precipitated dimethylamine hydrobromide (3·2 g.) and evaporated under reduced pressure. The residual oil was dissolved in ether, filtered, and extracted with dilute hydrochloric acid. The acid solution was strongly basified and extracted with ether. 1-Cyano-3-dimethylamino-1-phenylindane hydrochloride (β) was precipitated from the dry ether solution with dry hydrogen chloride and recrystallised from ethyl acetate–ethanol after drying *in vacuo* over sodium hydroxide. It formed colourless needles, m. p. 193—212°, mixed m. p. with α-hydrochloride 193—208° (Found: C, 72·5; H, 6·3; N, 9·35. Calc. for $C_{18}H_{18}N_2,HCl$: C, 72·35; H, 6·4; N, 9·4%). The picrate, recrystallised from ethanol, had m. p. 195—198°, mixed m. p. with α-picrate 195—198° (Found: C, 58·6; H, 4·5; N, 14·5%).

(*c*) 3-Bromo-1-cyano-1-phenylindane prepared from indane-B (3·5 g.) was allowed to react with dimethylamine (2·4 c.c.) as in the previous experiment. After filtration, evaporation, and dissolution in ether, the refiltered solution was extracted with dilute hydrochloric acid. A copious precipitate was formed which was collected and recrystallised from ethyl acetate–ethanol, giving colourless needles of 1-cyano-3-dimethylamino-1-phenylindane hydrochloride (γ), m. p. 221° (decomp.), mixed m. p. with β-hydrochloride 173°, with α-hydrochloride 182°, with γ-hydrochloride (below) 220° (decomp.).

The residual acid solution above was strongly basified and extracted with ether and 1-cyano-3-dimethylamino-1-phenylindane hydrochloride (β) precipitated in the usual way. Crystallisation from ethyl acetate–ethanol gave needles, m. p. 193—212°, mixed m. p. with β-hydrochloride 193—212°.

(*d*) A similar experiment with the bromocyanophenylindane prepared from indane-C gave needles of 1-cyano-3-dimethylamino-1-phenylindane hydrochloride (γ), m. p. 216—218°, mixed m. p. with γ-hydrochloride (below) 219—220°.

The residual acid solution was basified and extracted with ether. From this the γ-hydrochloride was obtained in the usual way, m. p. 216—218°. The picrate, recrystallised from ethanol, had m. p. 184°, mixed m. p. with γ-picrate (below) 179°, with β-picrate 172—176°.

(*e*) 1-Cyano-1-phenylindane-A (8·5 g.) and bromine (1·95 c.c.) were heated under reflux in dry carbon tetrachloride in the presence of a trace of benzoyl peroxide. The reaction was complete in 6 hr. Evaporation of the solvent under reduced pressure gave the bromo-derivative as a red gum which was dissolved in dioxan and treated with dimethylamine (3 mols.). The mixture was slowly warmed to 60° and allowed to cool overnight. After filtration, evaporation, and dissolution in ether, the refiltered solution was extracted with dilute hydrochloric acid. There was some precipitate which dissolved on addition of more water. The acid solution was strongly basified and extracted with ether. 1-Cyano-3-dimethylamino-1-phenylindane hydrochloride (γ) was prepared from this in the usual way, as needles, m. p. 221° (Found: C, 71·8; H, 6·4; N, 9·1%). The *γ-picrate*, recrystallised from ethanol, had m. p. 181°, mixed m. p. with β-picrate 172—176°, with α-picrate 168—185° (decomp.) (Found: C, 58·4; H, 4·2; N, 13·8. $C_{18}H_{18}N_2,C_6H_3O_7N_3$ requires C, 58·6; H, 4·3; N, 14·3%). The free base had *M* 202 ($C_{18}H_{18}N_2$ requires *M*, 262).

3-*Dimethylamino*-1-*ethoxycarbonyl*-1-*phenylindane*.—A solution of 1-cyano-3-dimethylamino-1-phenylindane (β) (2·0 g.) in dry ethanol (25 c.c.) was saturated at 0° with dry hydrogen chloride, then heated in a sealed tube for 24 hr. at 125°. Two immiscible layers had formed but the whole was evaporated under reduced pressure and dried *in vacuo* over sodium hydroxide. The residual gum was dissolved in chloroform and filtered from the precipitated ammonium chloride. Evaporation of the chloroform gave a sticky gum which was dissolved in water, basified with sodium carbonate, and extracted with ether. 3-*Dimethylamino*-1-*ethoxycarbonyl*-1-*phenylindane hydrochloride* was precipitated with hydrogen chloride in the usual way and dried *in vacuo* over sodium hydroxide; recrystallised from ethyl acetate–ethanol, it had m. p. 205° (Found:

C, 69·3; H, 7·0; N, 4·1. $C_{20}H_{23}O_2N$,HCl requires C, 69·4; H, 7·0; N, 4·05%). The *picrate* had m. p. 193—194° (Found: C, 58·4; H, 4·8; N, 10·3. $C_{20}H_{23}O_2N$,$C_6H_3O_7N_3$ requires C, 58·0; H, 4·9; N, 10·4%).

The residual sodium carbonate solution (above) was acidified with dilute hydrochloric acid and evaporated to dryness. The resulting semisolid mass was extracted with chloroform, and the solution filtered, dried, and evaporated, giving 3-dimethylamino-1-phenylindane-1-carboxylic acid as a sticky gum, which was converted into a *picrate*, m. p. 198° (from ethanol) (Found: C, 56·2; H, 4·6; N, 10·8. $C_{18}H_{19}O_2N$,$C_6H_3O_7N_3$ requires C, 56·4; H, 4·35; N, 11·0%).

Only slightly impure starting material was obtained by heating the nitrile in saturated ethanolic hydrogen chloride under reflux for 7 hr. and then for 4 hr. in a Carius tube at 100°.

Attempted Hydrolysis of 1-*Cyano*-3-*dimethylamino*-1-*phenylindane* (γ).—As in the previous experiment, 1-cyano-3-dimethylamino-1-phenylindane hydrochloride (γ) (2·0 g.) was heated with ethanolic hydrogen chloride in a sealed tube at 140° for 17 hr. Working up as previously gave a hydrochloride, m. p. 194—195°, from which was obtained a small amount of 3-*dimethylamino*-1-*phenylindane*-1-*carboxyamide picrate*, which, crystallised from ethanol, had m. p. 186° (Found: C, 54·6; H, 4·6; N, 12·7. $C_{18}H_{20}ON_2$,$C_6H_3O_7N_3$,H_2O requires C, 54·6; H, 4·7; N, 13·3%).

Attempted Preparation of 3-*Dimethylamino*-1-*phenyl*-1-*propionylindane*.—A solution of ethyllithium was prepared in dry ether from lithium (0·78 g.) and ethyl bromide (6·1 g.) and siphoned under nitrogen through a muslin filter into a nitrogen-filled flask. Ether and unchanged ethyl bromide were distilled off, and dry ether was added to the residue, followed by an ethereal solution of 1-cyano-3-dimethylamino-1-phenylindane (β) (2·62 g.) dropwise with stirring. The mixture was boiled for 17 hr. under nitrogen and poured on ice, and the ethereal layer separated, combined with the ethereal washings from the aqueous layer, and extracted with hydrochloric acid. The acid solution was heated on the steam-bath for 2 hr., cooled, filtered from a little dark oil, and basified strongly, and the basic material isolated with ether and converted into a *hydrochloride*, which crystallised from ethanol–ethyl acetate–ether in needles, m. p. 181°, mixed m. p. with hydrochloride of starting material 166°, with 1-dimethylamino-3-phenylindane hydrochloride[1] (m. p. 190°) 160—170° (Found: C, 70·9, 71·0; H, 7·5, 7·3; N, 5·0, 4·8. $C_{17}H_{19}N$,HCl,H_2O requires C, 70·0; H, 7·5; N, 4·8%). The *picrate* crystallised from ethanol (Found: C, 59·1; H, 4·6; N, 12·1. $C_{17}H_{19}N$,$C_6H_3O_7N_3$ requires C, 59·1; H, 4·7; N, 12·0%).

A reaction conducted between the nitrile and ethylmagnesium iodide in toluene at 97° for 18 hr. led to recovery of the starting material, and another similar reaction in anisole at 150° for 20 hr. gave no basic material.

Ethyl γ-*Oxo*-ββ-*diphenylvalerate*.—(*a*) Ethyl hydrogen αα-diphenylsuccinate[5] (7·45 g.) was converted into the half ester chloride by reaction with thionyl chloride followed by evaporation under reduced pressure. Methylmagnesium chloride (from magnesium, 1·15 g., and methyl chloride in ether) was treated at 0° with cadmium chloride (5·0 g.) and stirred until a negative test with Michler's ketone was obtained. A dry ethereal solution of the acid chloride was added to the cooled solution of dimethylcadmium, yielding a sticky solid. The mixture was heated under reflux for 4 hr. and set aside overnight. It was then decomposed with ice and dilute hydrochloric acid, and the ether layer separated. The aqueous layer was extracted with ether, and the combined ether solutions were washed with dilute hydrochloric acid, water, and then sodium carbonate solution until all acid had been removed. The ether solution was dried (K_2CO_3) and the residue distilled *in vacuo* to give the *valerate* (2·5 g., 33·8%), b. p. 143—145°/0·07 mm. (Found: C, 77·0; H, 6·7. $C_{19}H_{20}O_3$ requires C, 77·0; H, 6·8%).

A similar experiment under more drastic conditions was carried out on the acid chloride from the half-ester (15·4 g.). A toluene solution of this was added to an ether–toluene solution of dimethylcadmium [prepared from methylmagnesium chloride (7 g. of magnesium) and anhydrous cadmium chloride (30·3 g.)], and the ether was distilled off until the internal temperature was 70°. The mixture was heated under reflux for 3 hr. and set aside overnight. A non-acidic brown gum was isolated by the procedure above and hydrolysed to a yellow oily acid (6·3 g.). Purification by acidification of the sodium carbonate extracts gave γ-*hydroxy*-γ-*methyl*-αα-*diphenylvaleric acid* which, crystallised from ethanol, had m. p. 202—203° (Found: C, 76·5; H, 7·4%; *M*, 252. $C_{18}H_{20}O_3$ requires C, 76·1; H, 7·0%; *M*, 284).

(*b*) To a stirred mixture of ether (80 c.c.) and 40% potassium hydroxide solution (24 c.c.), cooled to 5°, *N*-nitrosomethylurea (8 g.) was added in portions. Then the solution was stirred at 5° for 10 min., the layers were separated, and the ether solution of diazomethane (containing 2·24 g.) dried (KOH). This solution was stirred at 0° and an ether solution of the half-ester acid

chloride (from 5·0 g. of the half-ester above) added dropwise. The yellow solution was stirred at 0° for ½ hr., then at room temperature for 3 hr., and set aside overnight. The ether was evaporated to 25°, to give a yellow semicrystalline material which was kept at −5°. A solution of this diazo-ketone (0·5 g.) in dry chloroform was shaken with 55% hydriodic acid (2 c.c.). A gas was evolved and the chloroform layer was separated, dried, and evaporated *in vacuo*. The residual gum was dissolved in ether, decolorised by a little sodium thiosulphate solution, washed with sodium hydrogen carbonate solution, dried, and evaporated. The residual brown gum, crystallised from aqueous methanol, gave the *keto-ester* as needles, m. p. 97° (Found: C, 73·2; H, 6·6. $C_{19}H_{20}O_3,H_2O$ requires C, 72·6; H, 7·0%).

Reaction between Ethylmagnesium Iodide and 1-*Cyano*-3-*oximino*-1-*phenylindane.*—Ethylmagnesium iodide was prepared from ethyl iodide (5·0 g.) and magnesium (0·8 g.) in ether, the ether replaced by toluene (10 c.c.), and the whole heated at 130—140°. A solution of 1-cyano-3-oximino-1-phenylindane (1·0 g.) in dry toluene (10 c.c.) was slowly added to the hot solution during 15 min. and heating was continued for a further 20—30 min. The solution was cooled, hydrolysed with ice and ammonium chloride, and extracted with ether. The basic material was isolated by extracting the ethereal solution with acid and then basifying. 1 : 2-*Imino*-3-*phenylindane picrate* crystallised from ethanol in plates, m. p. 202—203° (decomp.) (Found: C, 59·2; H, 4·0; N, 11·7. $C_{17}H_{17}N,C_6H_3O_7N_3$ requires C, 59·5; H, 4·3; N, 12·1%).

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Dyson Perrins Laboratory, Oxford. [*Received, August 3rd,* 1955.]

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140. *Compounds of Potential Pharmacological Interest. Part II.* Some Heterocyclic and Carbocyclic Systems Related to* 1-*Phenylindane.*

By R. M. Acheson, K. E. MacPhee, P. G. Philpott, and J. A. Barltrop.

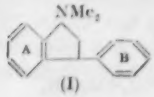
Attempts to prepare the thiophen analogues of 1-dimethylamino-3-phenylindane are described. 3′-Dimethylamino-5′-phenyl*cyclo*penteno(1′ : 2′-2 : 3)thiophen (IV) has been synthesised from phenyl 2-thienyl ketone. 9-Dialkylaminoalkyl-9-ethoxycarbonyl-xanthen and -dihydroanthracene have been obtained by alkylating the potassio-derivatives of 9-ethoxycarbonylxanthen and -dihydroanthracene with primary dialkylaminoalkyl halides. A similar alkylation in the xanthen series, involving the secondary halide, 2-chloro-1-dimethylaminopropane, led to the amino-ester (XXIII) formed by reaction at the ester group. 9-Dimethylaminoxanthen has also been prepared.

In Parts I * and IV [1] are reported the analgesic activity associated with 1-dimethylamino-3-phenylindane (I) and attempts to augment the activity of the system by structural modifications. This communication is concerned with a similar investigation into the behaviour of related heterocyclic compounds. Replacement of a benzene ring in a pharmacologically active substance by a thiophen nucleus sometimes increases the activity but rather more frequently decreases it (see the thienyl analogues of amidone and pethidine [2]). However, some 3-dialkylamino-1 : 1-di-2′-thienyl-but-1-enes (II) and -butanes (III), prepared by Adamson,[3] exhibited such high analgesic acitivity as to encourage us to pursue similar investigations and in particular to synthesise the compounds (IV) and (V), which are related cyclically to Adamson's substances.

* Part I, preceding paper.

[1] Acheson, Philpott, MacPhee, Hunt, and Barltrop, to be published.
[2] Blicke, U.S.P. 2,425,721; Brown, Cook, and Heilbron, *J.*, 1949, S 113; Leonard and Ehrenthal, *J. Amer. Chem. Soc.*, 1951, **73**, 2216.
[3] Adamson, *J.*, 1950, 885; *Nature*, 1950, **165**, 122; 1951, **167**, 153.

Attempts to prepare β-phenyl-β-2-thienylpropionic acid (VI; R = H) as an intermediate by alkylating thiophen with cinnamic acid (cf. Pfeiffer and de Waal,[4] for the preparation of 3 : 3-diphenylpropionic acid) in presence of aluminium chloride or boron trifluoride, led to recovery of most of the cinnamic acid and destruction of the bulk of the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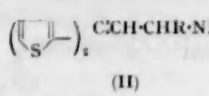
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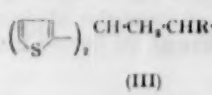
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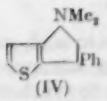
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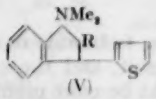
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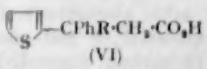
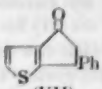

(VI)

thiophen, though in one case a very low yield of the ketone (VII) was obtained. In an alternative approach a Reformatsky reaction between phenyl 2-thienyl ketone [5] and ethyl bromoacetate gave an 86% yield of ethyl β-hydroxy-β-phenyl-β-2-thienylpropionate (as VI; R = OH) which was dehydrated by aqueous oxalic acid [6] to the acrylic ester. This, on reduction with sodium amalgam and hydrolysis, gave the desired propionic acid (VI; R = H) in 78% yield. Efforts to cyclise the derived acid chloride with aluminium chloride, or with stannic chloride in carbon disulphide or benzene, resulted in resins from which traces of ketonic material but no acid could be isolated. Ultimately, under precisely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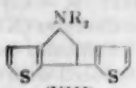
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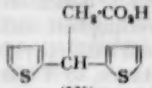
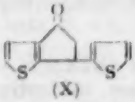

(IX)

defined conditions, polyphosphoric acid was found to cyclise the acid to a ketone albeit in only moderate yields. That the cyclisation involved the thiophen rather than the benzene ring, and gave (VII), was proved by first desulphurising the ketone with Raney nickel [7] and then oxidising the product with alkaline potassium permanganate: benzoic acid was obtained in 33% yield and no phthalic acid.

The ketone (VII) was reduced to the alcohol by lithium aluminium hydride, and this was converted into the bromide and then allowed to react with dimethylamine. 3'-Dimethylamino-5'-phenyl*cyclo*penteno(1' : 2'-2 : 3)thiophen (IV), so obtained, appeared to exist as a mixture of *cis–trans*-isomers, which were separated.

An attempt was now made to prepare the bases (VIII) in which both rings A and B in the phenylindane (I) were replaced by thiophen nuclei. 2-Thienoic acid was prepared by a modification of Gilman and Shirley's method [8] and converted into 2 : 2'-dithienyl ketone by condensing it with thiophen in the presence of phosphoric oxide. This ketone was converted, as in the previous case, into ββ-di-2-thienylpropionic acid (IX). It was found to be impossible to cyclise this acid, even polyphosphoric acid yielding only tars. Pre-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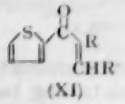
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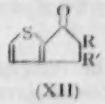
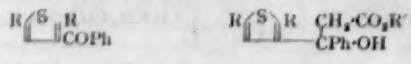

(XII)

sumably, these difficulties arise from the facility of intermolecular condensation involving the reactive position 5 of the thiophen ring, compared with the difficulty of intramolecular condensation on to the relatively inert position 3; the substance (IX) with two such reactive positions would be expected to be more intractable than (VI; R = H) which possesses only one.

[4] Pfeiffer and de Waal, *Annalen*, 1935, **520**, 185.
[5] Minnis, *Org. Synth.*, Coll. Vol. II, p. 520.
[6] Cf. Miller and Nord, *J. Org. Chem.*, 1950, **15**, 89.
[7] Cf. Blicke and Sheets, *J. Amer. Chem. Soc.*, 1949, **71**, 4010.
[8] Gilman and Shirley, *ibid.*, p. 1870.

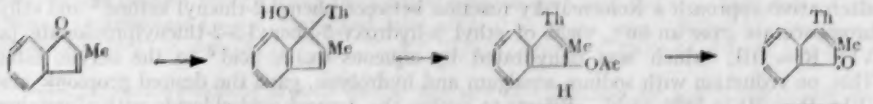
Equally unsuccessful was an attempt to prepare the intermediate (XII; R = H, R′ = Ph). Burckhalter and Sam [9] reported the cyclisation of the olefin (XI; R = Me, R′ = H) to the ketone (XII; R = Me, R′ = H) by means of concentrated sulphuric acid, but styryl 2-thienyl ketone (XI; R = H, R′ = Ph), under the catalytic influence of



(XIII) (XIV)

(XIX)

sulphuric acid, aluminium chloride, boron trifluoride or polyphosphoric acid, gave only starting material or red gums. This result, and the considerations advanced in the previous paragraph, suggested that it might be more profitable to turn to syntheses which depended on cyclisation on to the position 2 of the thiophen ring.



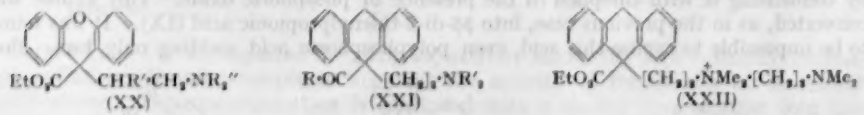
(XV) (XVI) (XVII) (XVIII)

(Th = 2-thienyl.)

3-Benzoyl-2 : 5-dichlorothiophen (XIII; R = Cl) was obtained by benzoylation of 2 : 5-dichlorothiophen, and converted into the ester (XIV; R = Cl, R′ = Et) by a Reformatsky reaction with ethyl bromoacetate. Difficulty was experienced with the dehydration of this substance, so it was immediately reduced with sodium amalgam, giving the dehalogenated acid (XIV; R, R′ = H). Further experiments along this route are proceeding.

A more promising reaction sequence suggested by the work of Burton and Shoppee [10] appeared to be (XV) ⟶ (XVIII). 2-Methylindenone (XV) [10] and 2-thienylmagnesium iodide gave 1-hydroxy-2-methyl-1-2′-thienylindene (XVI), which on acetylation gave the acetoxy-compound (XVII). This, on hydrolysis with alcoholic potassium hydroxide, underwent a prototropic rearrangement to the thienylindanone (XVIII). The transformation of this substance into the amine (V; R = Me) is under investigation.

Another aspect of this work, studied simultaneously, was the synthesis of molecules of the types (XIX), (XX), and (XXI), which are carbocyclic and heterocyclic analogues of the amidone group of analgesics. Ethyl 9 : 10-dihydroanthracene-9-carboxylate, prepared in excellent yield by carboxylating the lithio-derivative of dihydroanthracene and esterifying the acid, was converted into its potassio-derivative and alkylated in toluene with 2-diethylaminoethyl chloride, giving the amine (XIX; R = Et). An attempt



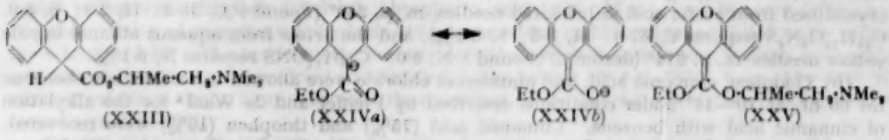
(XX) (XXI) (XXII)

to prepare the corresponding 2-dimethylaminoethyl derivative (XIX; R = Me) under similar conditions gave a product containing two basic residues, evidently (XXII), in which further alkylation of the primary product (XIX; R = Me) had occurred.

Attempts to prepare the amino-ketone (XXI; R = R′ = Et) by alkylating 9 : 10-dihydro-9-propionylanthracene [11] with diethylaminoethyl chloride in the presence of sodamide gave only degradation products, from which ultimately anthracene and anthraquinone were isolated. Further investigation was curtailed by the publication of the successful synthesis of this and related compounds by Cusic.[12]

[9] Burkhalter and Sam, *ibid.*, 1951, **73**, 4460.
[10] Burton and Shoppee, *J.*, 1935, 1156.
[11] May and Mosettig, *J. Amer. Chem. Soc.*, 1948, **70**, 688.
[12] Cusic, U.S.P. 2,551,316.

Analogous compounds (XX; R′ = H, R″ = Me and Et) were prepared similarly from ethyl xanthen-9-carboxylate. However, reaction with 2-chloropropyldimethylamine was very slow and the product had the formula $C_{19}H_{21}O_3N$ instead of the expected $C_{21}H_{25}O_3N$: clearly, an ethyl group had been lost. There are two likely structures for the substance: first, an amino-acid formulation (XX; R′ = R″ = Me, CO_2H replacing CO_2Et), which was excluded because of the insolubility of the substance in alkali; and, secondly, the amino-ester formulation (XXIII), which was proved by alkaline hydrolysis to xanthen-9-carboxylic acid.



(XXIII) (XXIV*a*) (XXIV*b*) (XXV)

This anomalous alkylation presumably occurs because the potassio-derivative of ethyl xanthen-9-carboxylate is mesomeric (XXIV*a* ◄► *b*). With primary alkyl halides, alkylation proceeds predominantly on $C_{(9)}$ *via* the canonical form (*a*). However, $C_{(9)}$ is less accessible than the negatively charged oxygen atom in (XXIV*b*), and with the more hindered secondary halides substitution at this point is so retarded that the main reaction takes place at the oxygen atom, leading to the keten acetal (XXV). This would be hydrolysed under the acidic working-up procedures to the ester (XXIII) or to ethyl xanthen-9-carboxylate. This abnormal alkylation finds a parallel in the work of Laakso[13] who showed that certain dithio-esters, when alkylated, gave keten mercaptals.

Finally, the synthesis of 9-dimethylaminomethylxanthen was accomplished by reducing *NN*-dimethylxanthen-9-carboxyamide with lithium aluminium hydride.

Through the courtesy of Dr. G. E. Ullyot, these compounds were examined pharmacologically by Smith, Kline and French Laboratories, Philadelphia. Significant analgesic activity was not observed in these substances. 9-Dimethylaminomethylxanthen showed activity as an antihistaminic (demonstrated by protection afforded to guinea pigs in bronchospasm induced by histamine) and as a sedative for the central nervous system. The amino-esters of the xanthen series possessed antispasmodic activity.

Experimental

Ethyl β-Hydroxy-β-phenyl-β-2-thienylpropionate.—A mixture of phenyl 2-thienyl ketone[5] (38·8 g.), ethyl bromoacetate (14 g.), zinc turnings (17 g.), and benzene (200 c.c.) was boiled under reflux for 4 hr. The mixture was cooled and decomposed with ice and sulphuric acid, and the benzene layer separated, washed with water, sodium hydrogen carbonate solution, and water, dried and evaporated. The solid residue, when crystallised from ligroin (b. p. 40—60°) gave the desired *ester* (49 g., 86%) as needles, m. p. 65—66° (Found: C, 65·4; H, 6·0; S, 11·9. $C_{16}H_{16}O_3S$ requires C, 65·3; H, 5·8; S, 11·6%).

Ethyl β-Phenyl-β-2-thienylacrylate.—The preceding hydroxy-ester (48 g.) was boiled under reflux for 3 hr. with 6% aqueous oxalic acid (500 c.c.). The oily layer was separated, dried, and distilled. *Ethyl β-phenyl-β-2-thienylacrylate* (40 g., 83%) was collected at 135—140°/0·2 mm. (Found: C, 70·1; H, 5·5; S, 12·7. $C_{16}H_{14}O_2S$ requires C, 69·8; H, 5·4; S, 12·4%).

Hydrolysis gave the *acrylic acid*, which crystallised from ligroin in colourless elongated needles, m. p. 136—137° (Found: C, 68·1; H, 4·6; S, 13·7. $C_{14}H_{10}O_2S$ requires C, 67·8; H, 4·4; S, 13·9%).

β-Phenyl-β-2-thienylpropionic Acid.—A mixture of ethyl β-phenyl-β-2-thienylacrylate (40 g.), sodium amalgam (3%; 960 g.), and ethanol (500 c.c.) was boiled under reflux for 7 hr. The solution was decanted from mercury, diluted with water (200 c.c.), and boiled for a further 2 hr. The bulk of the ethanol was distilled off, and the residual solution was washed with ether and acidified. The precipitated acid was crystallised from ligroin. The *propionic acid* (28·2 g., 78%) formed colourless needles, m. p. 147—148° (Found: C, 67·0; H, 5·14; S, 13·9. $C_{13}H_{12}O_2S$ requires C, 67·3; H, 5·2; S, 13·8%). The *amide* separated from water in needles, m. p. 115—116° (Found: C, 67·8; H, 5·7; N, 6·2; S, 13·6. $C_{13}H_{13}ONS$ requires C, 67·6; H, 5·6; N, 6·1; S, 13·9%).

[13] Laakso, *Suomen Kem.*, 1944, **17**, *B*, 1, 3.

3'-Oxo-5'-phenylcyclopenteno(1' : 2'-2 : 3)thiophen.—(*A*) β-Phenyl-β-2-thienylpropionic acid (1·5 g.) was added to a stirred mixture of phosphoric anhydride (10 g.) in phosphoric acid (85%; 9 c.c.) at 145—150° and kept at that temperature for 5 min. The mixture was diluted with ice and extracted with ether (3 × 30 c.c.). The extract was washed with water, sodium carbonate solution, and water, and dried. Unchanged acid was recovered from the sodium carbonate washings. In total, 33 g. of acid were treated in this manner. The ether solution was evaporated and the residue distilled. The *ketone* (11·5 g., 35%) was collected at 130—135°/0·1 mm. It crystallised from ligroin in pale yellow rhombs, m. p. 93—94° (Found : C, 73·2; H, 5·0; S, 14·7. $C_{13}H_{10}OS$ requires C, 72·9; H, 4·7; S, 15·0%). The 2 : 4-*dinitrophenylhydrazone* crystallised from acetic acid in brick-red needles, m. p. 250° (Found : C, 58·3; H, 3·9; S, 8·0. $C_{19}H_{14}O_4N_4S$ requires C, 57·8; H, 3·6; S, 8·1%), and the *oxime* from aqueous ethanol in pale yellow needles, m. p. 214° (decomp.) (Found : N, 6·0. $C_{13}H_{11}ONS$ requires N, 6·1%).

(*B*) Thiophen, cinnamic acid, and aluminium chloride were allowed to react in nitrobenzene for 60 hr. at 10—15° under conditions described by Pfeiffer and de Waal[14] for the alkylation of cinnamic acid with benzene. Cinnamic acid (75%) and thiophen (10%) were recovered. Vacuum-distillation gave a very low yield of a ketonic oil. The 2 : 4-dinitrophenylhydrazone had m. p. 250° alone and when mixed with the dinitrophenylhydrazone described above.

Degradation of 3'-Oxo-5'-phenylcyclopenteno(1' : 2'-2 : 3)thiophen.—A mixture of the ketone (1 g.), Raney nickel[14] (40 g.), and ethanol (200 c.c.) was boiled under reflux for 30 min., cooled, and filtered. The ethanol washings from the catalyst were combined with the filtrate and evaporated. The residual, sweet-smelling oil was boiled with stirring for 4 hr. with a solution of potassium hydroxide (3·4 g.) and potassium permanganate (9·5 g.) in water (300 c.c.). The cool mixture was decolorised with sulphur dioxide, strongly acidified, and extracted with ether (3 × 60 c.c.). The ethereal solution was extracted with sodium hydrogen carbonate solution, and the aqueous phase acidified, and extracted several times with ether. Evaporation of the dried ethereal solution gave a solid residue, which on sublimation *in vacuo* gave benzoic acid (0·2 g., 33%), m. p. and mixed m. p. 122°

3'-Hydroxy-5'-phenylcyclopenteno(1' : 2'- 2 : 3)thiophen.—3'- Oxo - 5'- phenylcyclopenteno-(1' : 2'-2 : 3)thiophen (7·8 g.) in dry ether (200 c.c.) was boiled with lithium aluminium hydride (0·45 g.) in ether (200 c.c.) for 1 hr. On cooling, excess of reagent was destroyed with a few drops of water and the complex decomposed with 10% sulphuric acid. The ether layer was separated, and the aqueous layer extracted with ether (3 × 30 c.c.). The combined ether fractions were washed with water, sodium hydrogen carbonate solution, and water and dried ($MgSO_4$). On removal of the ether the residue solidified. *3'-Hydroxy-5'-phenylcyclopenteno-(1' : 2'-2 : 3)thiophen* (6·6 g., 85%) crystallised from ligroin in colourless needles, m. p. 133—134° (Found : C, 72·1; H, 5·6; S, 14·6. $C_{13}H_{12}OS$ requires C, 72·2; H, 5·6; S, 14·8%).

3'-Dimethylamino-5'-phenylcyclopenteno(1' : 2'-2 : 3)thiophen.—A solution of 3'-hydroxy-5'-phenylcyclopenteno(1' : 2'-2 : 3)thiophen (7·2 g.) in benzene (300 c.c.) was saturated with hydrogen bromide at 0°. Water separated and in an hour the solution became dark greenish-blue. The benzene solution was washed with water, 5% sodium hydrogen carbonate solution, and water, and the benzene removed under reduced pressure. The residue was dissolved in dry dioxan (30 c.c.) and together with anhydrous dimethylamine (7 g.) was transferred to a pressure bottle at 0°. Reaction was allowed to proceed for 12 hr. at room temperature. The dimethylamine hydrobromide was collected and the filtrate concentrated under reduced pressure. The residual oil was dissolved in dry ether and saturated with dry hydrogen chloride at 0°. After 1 hr. the ether was decanted and the gummy solid dried *in vacuo* over sodium hydroxide. *3'-Dimethylamino-5'-phenylcyclopenteno(1' : 2'-2 : 3)thiophen hydrochloride* (*isomer A*; 2·5 g.) crystallised from ethyl acetate–ethanol in colourless needles, m. p. 196—197° (Found : C, 64·3; H, 6·7; S, 11·8. $C_{15}H_{17}NS,HCl$ requires C, 64·4; H, 6·4; S, 11·5%). The *picrate* (of isomer A) separated from ethanol in bright yellow needles, m. p. 150—151° (Found : C, 53·8; H, 4·3. $C_{15}H_{17}NS,C_6H_3N_3O_7$ requires C, 53·4; H, 4·2%).

The mother-liquors from crystallisation of isomer A yielded an isomeric (*B*) *amine hydrochloride*, which crystallised from ethyl acetate–ethanol in colourless rhombs (2 g.), m. p. 150—151° (Found : C, 64·2; H, 6·5; S, 11·2%). The derived *picrate* separated from ethanol in yellow needles, m. p. 129—130° (Found : C, 53·6; H, 4·2; N, 11·6%).

A saturated solution of isomer B in ethyl acetate–ethanol, seeded with isomer A, does not give isomer A; isomer B is recovered unchanged.

2-Thienoic Acid.—A solution of *n*-butyl bromide (54·8 g.) in dry ether (100 c.c.) was added

[14] Mozingo, Wolf, Harris, and Folkers, *J. Amer. Chem. Soc.*, 1943, **65**, 1013.

in an atmosphere of dry nitrogen to a stirred mixture of small strips of lithium (8 g.) in dry ether (300 c.c.). When reaction was complete, the solution was blown, under pressure of nitrogen, through small-bore tubing into a two-necked flask containing a stirred solution of thiophen (16·8 g.) in ether (100 c.c.). The mixture was stirred for a further 15 min. and then blown (by nitrogen) through tubing on to a stirred slurry of crushed solid carbon dioxide and ether. Water (100 c.c.) was added cautiously to the mixture. The aqueous layer was separated and acidified with concentrated hydrochloric acid, and the 2-thienoic acid collected. This (18·2 g., 71%) crystallised from ligroin in colourless needles, m. p. 128°.

Di-2-thienyl Ketone.—2-Thienoic acid (36·5 g.) in benzene (300 c.c.) was boiled for 2 hr. under reflux with thiophen (25·2 g.), phosphoric anhydride (48 g.), and benzene (300 c.c.). Another portion of phosphoric anhydride (48 g.) was added and the mixture boiled under reflux for a further 2 hr. The benzene solution was decanted, washed with water, sodium hydroxide solution, and water, and then dried and distilled. The ketone (36·4 g., 66%), b. p. 185—190°/10 mm., crystallised from ligroin in colourless needles, m. p. 88—89°. Hartough and Kosak [15] record a yield of 50%.

Ethyl β-Hydroxy-ββ-di-2-thienylpropionate.—A mixture of di-2-thienyl ketone (36·4 g.), ethyl bromoacetate (40 g.), and zinc turnings (15 g.) in dry benzene (400 c.c.) was boiled under reflux for 4 hr. The mixture was cooled and decomposed with 10% sulphuric acid. The benzene layer was separated, washed with water, 5% sodium hydrogen carbonate solution, and water, and the benzene removed under reduced pressure; the residue solidified. The *hydroxy-ester* crystallised from ligroin in colourless rods, m. p. 55—56° (Found: C, 55·7; H, 5·2; S, 22·6. $C_{13}H_{14}O_3S_2$ requires C, 55·3; H, 5·0; S, 22·7%).

Ethyl ββ-Di-2-thienylacrylate.—The crude hydroxy-ester, suspended in aqueous oxalic acid (500 c.c.; 6%), was boiled under reflux for 3 hr. The mixture was cooled, and the oil separated, dried, and distilled. The *acrylate* (35 g.) was collected at 140—145°/0·2 mm. (Found: C, 58·9; H, 4·3. $C_{13}H_{12}O_2S_2$ requires C, 59·1; H, 4·5%).

Hydrolysis afforded the *acrylic acid*, needles, m. p. 137° (from ligroin) (Found: C, 56·1; H, 3·6; S, 27·1. $C_{11}H_8O_2S_2$ requires C, 55·9; H, 3·4; S, 27·1%).

ββ-Di-2-thienylpropionic Acid.—Ethyl ββ-di-2-thienylacrylate (34 g.), sodium amalgam (3%; 800 g.), and ethanol (500 c.c.) were boiled under reflux for 11 hr., decanted from mercury, diluted with water (100 c.c.), and boiled under reflux for a further 2 hr. The bulk of the ethanol was removed under reduced pressure, the cooled aqueous solution acidified, and the precipitated acid collected and dried at 100°. *ββ-Di-2′-thienylpropionic acid* (22·2 g.) crystallised from ligroin in colourless needles, m. p. 118° (Found: C, 55·6; H, 4·5; S, 27·0. $C_{11}H_{10}O_2S_2$ requires C, 55·4; H, 4·2; S, 26·9%). The *amide* separated from water in needles, m. p. 126° (Found: C, 55·3; H, 4·3; N, 5·8; S, 27·4. $C_{11}H_{11}ONS_2$ requires C, 55·7; H, 4·6; N, 5·9; S, 27·0%).

Styryl 2-Thienyl Ketone.[16]—Sodium (0·5 g.) was dissolved in ethanol (10 c.c.) and added to a solution of 2-acetylthiophen [15] (5 g.) and benzaldehyde (4·2 g.) in ethanol (50 c.c.), and the solution kept at 0° for 24 hr. Styryl 2-thienyl ketone was collected, washed with cold ethanol, and dried. It crystallised from ligroin in colourless rods, (7·1 g.) m. p. 85—86° (Brunswig gives m. p. 80°) (Found: C, 72·7; H, 4·8; S, 14·7. Calc. for $C_{13}H_{10}OS$: C, 72·9; H, 4·7; S, 15·0%).

3-Benzoyl-2 : 5-dichlorothiophen.—Powdered, aluminium chloride (37·5 g.) was added, during 30 min., to a stirred solution of 2 : 5-dichlorothiophen (38·3 g.) and benzoyl chloride (38 g.) in carbon disulphide (200 c.c.) at 15°. The mixture became deep black almost immediately. Stirring was continued for a further 2 hr. and the mixture then set aside at room temperature for 12 hr. The complex was decomposed with ice and concentrated hydrochloric acid. The carbon disulphide layer was washed with water, 10% sodium hydrogen carbonate solution (3 × 50 c.c.), and water, and dried, and distilled. *3-Benzoyl-2 : 5-dichlorothiophen* (16·8 g.) was collected at 125—130°/0·2 mm. It was a pale yellow mobile oil which darkened rapidly in light and air. The *2 : 4-dinitrophenylhydrazone* crystallised from acetic acid in orange needles, m. p. 208° (Found: C, 47·0; H, 2·6; N, 12·7; S, 6·9. $C_{17}H_{10}O_4N_4Cl_2S$ requires C, 46·7; H, 2·3; N, 12·8; S, 7·3%).

Ethyl β-(2 : 5-Dichloro-3-thienyl)-β-hydroxy-β-phenylpropionate.—A mixture of 3-benzoyl-2 : 5-dichlorothiophen (5 g.), zinc turnings (1·7 g.), and ethyl bromoacetate (3·5 g.) in dry benzene (100 c.c.) was heated under reflux for 4 hr. The mixture was cooled and decomposed with sulphuric acid. The benzene layer was separated, washed with water, sodium hydrogen

[15] Hartough and Kosak, *ibid.*, 1947, **69**, 3093.
[16] Cf. Brunswig, *Ber.*, 1886, **19**, 2895.

carbonate solution, and water, and dried, and distilled. The *hydroxy-ester* (5·5 g.), a yellow, mobile oil, was collected at 150—155°/0·2 mm. (Found: C, 52·5; H, 4·1; Cl, 20·3; S, 9·7. $C_{16}H_{14}O_3Cl_2S$ requires C, 52·2; H, 4·1; Cl, 20·6; S, 8·3%).

Hydrolysis afforded the *hydroxy-acid*, which crystallised from ligroin in pale brown needles, m. p. 115° (Found: C, 49·5; H, 3·5; Cl, 22·2; S, 9·9. $C_{13}H_{10}O_3Cl_2S$ requires C, 49·2; H, 3·2; Cl, 22·4; S, 10·1%).

An attempt to dehydrate the hydroxy-ester by 6% aqueous oxalic acid gave an unstable oil; hydrolysis of this afforded the hydroxy-acid, identified by analysis and mixed m. p. 115°. The impure hydroxy-ester (from the attempted dehydration) with 3% sodium amalgam (10 equivs.) in aqueous ethanol was heated under reflux for 10 hr.: this gave an acid which crystallised from ligroin in pale yellow rhombs, m. p. 114°, and still contained a small amount of halogen (Beilstein test). It may be impure β-hydroxy-β-phenyl-β-3-thienylpropionic acid (Found: C, 61·9; 60·8; H, 4·6, 4·4; S, 11·4, 11·8. Calc. for $C_{13}H_{12}O_3S$: C, 62·9; H, 4·8; S, 12·9%).

1-Hydroxy-2-methyl-1-2′-thienylindene.—A solution of 2-iodothiophen[17] (10·5 g.) and methyl iodide (7 g.) in dry ether (50 c.c.) was added to magnesium (1·3 g.), and the mixture heated under reflux for 4 hr. The solution was cooled and 2-methylindenone (6 g.) in dry ether (30 c.c.) was added. A transient red colour was formed, which during 3 hr. at room temperature became orange-yellow. The mixture was decomposed with saturated aqueous ammonium chloride, and the ether layer separated. The aqueous layer was extracted with ether (3 × 30 c.c.), and the combined ether extracts were washed as above, dried, and distilled, yielding 1-hydroxy-1:2-dimethylindene (0·9 g.), b. p. 110°/1 mm., in colourless rhombs (from ligroin), m. p. 84—85° (Found: C, 82·2; H, 7·3. Calc. for $C_{11}H_{12}O$: C, 82·5; H, 7·5%) (Stoermer and Laage[18] give m. p. 82°), and *1-hydroxy-2-methyl-1-2′-thienylindene* (4·5 g.), an orange-yellow viscous oil, b. p. 153—155°/1 mm. (Found: C, 74·0; H, 5·2; S, 13·6. $C_{14}H_{12}OS$ requires C, 73·6; H, 5·3; S, 14·0%).

1-Acetoxy-2-methyl-3-2′-thienylindene.—1-Hydroxy-2-methyl-1-2′-thienylindene (1 g.) and acetic anhydride (10 c.c.) were heated under reflux for 7 hr., during which the colour had changed from pale yellow to a deep purple. The mixture was poured into cold water (100 c.c.) to decompose the excess of acetic anhydride and extracted with ether (3 × 30 c.c.). The combined ether extracts were washed with water, sodium carbonate solution, and water, and dried, and distilled. *1-Acetoxy-2-methyl-3-2′-thienylindene* (0·4 g.) was obtained as a pale yellow oil, b. p. 125°/0·6 mm., forming rhombs, m. p. 100° (from ligroin) (Found: C, 71·5; H, 5·5; S, 12·2. $C_{16}H_{14}O_2S$ requires C, 71·1; H, 5·2; S, 11·9%).

2-Methyl-3-2′-thienylindan-1-one.—A solution of 1-acetoxy-2-methyl-3-2′-thienylindene (0·5 g.) in ethanolic potassium hydroxide (20 c.c.; 5%) was boiled under reflux for 2 hr. There was a colour change from yellow to red. The solution was poured into water (100 c.c.), and the aqueous mixture extracted with ether (3 × 30 c.c.). The ether extracts were washed with water, dried, and evaporated. The ketone (*ca.* 0·3 g.) was obtained as a dark red mobile oil. The *2:4-dinitrophenylhydrazone* crystallised from acetic acid in dark red plates, m. p. 198° (Found: C, 59·0; H, 4·1; N, 13·5. $C_{20}H_{16}O_4N_4S$ requires C, 58·8; H, 3·9; N, 13·7%).

Ethyl 9-2′-Diethylaminoethyl-9:10-dihydroanthracene-9-carboxylate.—Potassium (1·75 g., 1 atom-equiv.) was added in small pieces to a dry toluene solution of ethyl 9:10-dihydroanthracene-9-carboxylate (11·5 g., 1 mol.). The solution was stirred at room temperature for 2 hr. and then warmed gently to reflux for ½ hr., by which time all the potassium had dissolved. The brown suspension was cooled, freshly prepared 2-diethylaminoethyl chloride (6·1 g., 1 mol.) was added, and the solution was heated under reflux for 3 hr., then cooled and extracted with dilute hydrochloric acid. The acid solution was strongly basified and extracted with ether. The residue from the dried extracts was heated *in vacuo* at 100° for ½ hr. and then dried *in vacuo* over concentrated sulphuric acid to remove any residual 2-diethylaminoethyl chloride. The hydrochloride was prepared in the usual way but failed to crystallise. The *picrate*, crystallised from ethanol, had m. p. 104° (Found: C, 60·0; H, 5·6; N, 9·4. $C_{23}H_{29}O_2N,C_6H_3O_7N_3$ requires C, 60·0; H, 5·6; N, 9·7%).

An attempt to prepare the corresponding 2-dimethylaminoethyl compound under similar conditions gave *N-2-dimethylaminoethyl-N-2-(9-ethoxycarbonyl-9:10-dihydro-9-anthryl)ethyl-NN′-dimethylammonium chloride hydrochloride* (from ethyl acetate–ethanol), m. p. 226° (Found: C, 60·0; H, 7·8; N, 5·7. $C_{25}H_{35}O_2N_2Cl,HCl,2H_2O$ requires C, 59·6; H, 8·0; N, 5·6%). The *dipicrate*, crystallised from ethanol, had m. p. 212° (Found: C, 52·5; H, 4·9; N, 14·4. $C_{33}H_{35}O_2N_2,C_6H_3O_7N_3,C_6H_3O_7N_3$ requires C, 52·1; H, 4·7; N, 13·1%).

[17] Minnis, *Org. Synth.*, 1932, **12**, 44.

[18] Stoermer and Laage, *Ber.*, 1917, **50**, 981.

Ethyl Xanthen-9-carboxylate.—Xanthen-9-carboxylic acid (7·8 g.), prepared by carboxylating the lithio-derivative of xanthen, was esterified by saturated ethanolic hydrogen chloride under reflux for 2 hr. Next morning the solution was evaporated under reduced pressure, the residual oil was dissolved in ether, and the solution washed with sodium carbonate solution, dried, and evaporated, to give *ethyl xanthen-9-carboxylate* (7·45 g., 85·5%). Recrystallisation from aqueous ethanol gave plates, m. p. 58° (Found : C, 75·5; H, 5·5. $C_{16}H_{14}O_3$ requires C, 75·6; H, 5·6%).

Ethyl 9-2′-Dimethylaminoethylxanthen-9-carboxylate.—Ethyl xanthen-9-carboxylate (7·45 g.) was alkylated with 2-dimethylaminoethyl chloride (4·5 g., 1·4 mol.) under the conditions described for alkylation of the corresponding anthracene ester, to give *ethyl 9-2′-dimethylaminoethylxanthen-9-carboxylate hydrochloride hemihydrate* (3·7 g., 34%) which, crystallised from ethyl acetate–ethanol, had m. p. 194° (Found: C, 65·1; H, 7·0; N, 3·4. $C_{20}H_{23}O_3N,HCl,\frac{1}{2}H_2O$ requires C, 64·8; H, 6·71; N, 3·8%). The *picrate*, crystallised from ethanol, had m. p. 154° (Found : C, 55·9; H, 4·75; N, 10·6. $C_{20}H_{23}O_3N,C_6H_3O_7N_3$ requires C, 56·3; H, 4·7; N, 10·1%).

Ethyl 9-2′-Diethylaminoethylxanthen-9-carboxylate.—Ethyl xanthen-9-carboxylate (10·0 g.) was alkylated with 2-diethylaminoethyl chloride (5·35 g., 1 mol.) as for the 2′-dimethylamino-compound, to give the corresponding *hydrochloride hemihydrate* (6·4 g., 41%), m. p. 106° (from ethyl acetate) (Found : C, 65·9; H, 7·5; N, 3·3; loss at 110°/vac., 2·4. $C_{22}H_{27}O_3N,HCl,\frac{1}{2}H_2O$ requires C, 66·2; H, 7·3; N, 3·5; $\frac{1}{2}H_2O$, 2·3%). The derived *picrate*, crystallised from ethanol, had m. p. 151° (Found : C, 57·9; H, 5·2; N, 9·5. $C_{22}H_{27}O_3N,C_6H_3O_7N_3$ requires C, 57·7; H, 5·2; N, 9·6%).

Attempted Preparation of Ethyl 9-2′-Dimethylamino-1′-methylethylxanthen-9-carboxylate.—Ethyl xanthen-9-carboxylate (7·0 g.) was alkylated with 2-chloropropyldimethylamine (3·5 g., 1·05 mol.) under the same conditions as for the previous alkylations of this ester. Reaction was incomplete after 24 hours' heating under reflux. The cooled toluene solution was washed with water, and the basic product isolated by acid-extraction. The acid solution was strongly basified and extracted with ether, and a hydrochloride prepared in the usual way. Recrystallisation from ethyl acetate–ethanol gave colourless *2-dimethylamino-1-methylethylxanthen-9-carboxylate hydrochloride*, m. p. 190° (Found : C, 60·0; H, 7·2; N, 3·7; loss at 120°/vac., 7·8. $C_{19}H_{21}O_3N,HCl,1\frac{1}{2}H_2O$ requires C, 59·8; H, 6·9; N, 3·8; loss, 7·2%). At 140° partial sublimation occurred. The *picrate*, crystallised from ethanol, had m. p. 161° (Found : C, 55·4; H, 4·6; N, 10·4. $C_{19}H_{21}O_3N,C_6H_3O_7N_3$ requires C, 55·55; H, 4·5; N, 10·4%). The hydrochloride with alcoholic potassium hydroxide gave an acid, m. p. 198—202°, mixed m. p. with xanthen-9-carboxylic acid (m. p. 218°) 209—210°.

NN-*Dimethylxanthen-9-carboxyamide.*—Xanthen-9-carboxylic acid was converted into the acid chloride with thionyl chloride. An ether solution of this was added with stirring to aqueous (33% w/v) dimethylamine. The *dimethylamide* was collected and recrystallised from aqueous ethanol as needles (8 g., 71·5%), m. p. 140° (Found : C, 75·5; H, 6·15; N, 5·7. $C_{16}H_{15}O_2N$ requires C, 75·9; H, 6·0; N, 5·5%).

9-*Dimethylaminomethylxanthen.*—Finely powdered lithium aluminium hydride (1·52 g., 0·04 mol.) was heated under reflux with dry ether (250 c.c.) for 2 hr. A dry ether solution of the dimethylamide (7·6 g., 0·03 mol.) was added and the whole heated under reflux for 20 hr. The excess of lithium aluminium hydride was decomposed with a few drops of ethyl acetate and then water. Concentrated sodium hydroxide solution was added, and the aqueous layer extracted with ether. The ether solution was extracted with dilute hydrochloric acid, and the acid solution basified and extracted with ether. Evaporation of the dried extracts gave *9-dimethylaminomethylxanthen* (6·3 g., 88%), m. p. 94° (from aqueous methanol) (Found : C, 80·4; H, 6·9; N, 5·45. $C_{16}H_{17}ON$ requires C, 80·3; H, 7·2; N, 5·85%). The *hydrochloride*, crystallised from ethyl acetate–ethanol, had m. p. 229—230° (Found : C, 69·5; H, 6·6; N, 5·4. $C_{16}H_{17}ON,HCl$ requires C, 69·7; H, 6·6; N, 5·1%). The *picrate*, crystallised from ethanol, had m. p. 187° (decomp.) (Found : C, 56·7; H, 4·3; N, 12·2. $C_{16}H_{17}ON,C_6H_3O_7N_3$ requires C, 56·4; H, 4·3; N, 11·9%).

Grateful acknowledgment is made to the Ministry of Education for a F.E.T.S. award (to P. G. P.) and to Smith, Kline and French Laboratories for the pharmacological testing.

DYSON PERRINS LABORATORY, OXFORD. [*Received, July 13th*, 1955.]

141. *Compounds of Potential Pharmacological Interest. Part III.* 2-Substituted 1-Phenylindanes.*

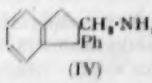
By J. A. Barltrop and R. F. Dodsworth.

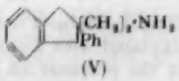
In the search for new analgesics and spasmolytics, two primary amines and one basic ester derived from 1-phenylindane have been synthesised.

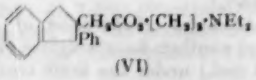
Diphenylmethyl and dialkylaminoethyl ester groupings are examples of important factors contributing to pharmacological activity; they can be found in many highly active compounds such as the analgesic amidone (I), the spasmolytic "Trasentin" (II), and the local anæsthetic procaine (III). The 4-phenylbutylamine system is also important. The

$Et\cdot CO\cdot CPh_2\cdot CH_2\cdot CHMe\cdot NMe_2$ (I) $\quad CHPh_2\cdot CO_2\cdot[CH_2]_2\cdot NEt_2$ (II) $\quad p\text{-}NH_2\cdot C_6H_4\cdot CO_2\cdot[CH_2]_2\cdot NEt_2$ (III)

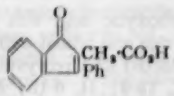
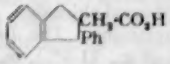
discovery[1,2] of a number of active compounds in the indane series suggested the investigation of indanamines and basic esters derived from 1-phenylindane, particularly (IV), (V), and (VI), since (IV) can be regarded as containing a 3-phenylpropylamine skeleton, and (V) contains a 4-phenylbutylamine skeleton, whilst (VI) is a basic ester of an indanylacetic acid, and all three compounds contain a diphenylmethyl grouping.


(IV)


(V)


(VI)

Syntheses of all three compounds started from the little known 1-oxo-3-phenyl-2-indenylacetic acid (VII) which was obtained in three stages from benzophenone through a Stobbe condensation[3] in good yield (average 67% of crude product). As expected, Clemmensen reduction of this αβ-unsaturated acid reduced both the double bond and the carbonyl group, and 1-phenyl-2-indanylacetic acid (VIII) was obtained in almost quantitative yield. The crude acid, melting over a range 105—140°, proved to be a mixture of the two possible geometrical isomers. The lower-melting and more soluble isomer was assigned the *cis*-configuration by analogy with previous facts.[4]

(VII)   (VIII)

The hydrochlorides of the required amines, *trans*-2-aminomethyl-1-phenylindane (IV) and *trans*-2-2′-aminoethyl-1-phenylindane (V), were obtained from *trans*-1-phenyl-2-indanylacetic acid by standard methods; the former by Hofmann degradation of the corresponding amide, and the latter from the same amide *via* the nitrile. Chlorine and sodium hydroxide solution having proved useless, the Hofmann degradation was successfully accomplished by using Jeffreys's procedure[5] which involves the use of bromine and sodium methoxide, the intermediate urethane being hydrolysed by dry distillation with excess of lime.

Of the available methods for the preparation of basic esters of carboxylic acids, the one involving the interaction of an acid with a chloroalkamine was chosen for the preparation of 2-diethylaminoethyl *trans*-1-phenyl-2-indanylacetate hydrochloride (as VI) since yields are generally good and products are relatively pure. The required chloroalkamine was

* Part II, preceding paper.

[1] Acheson, MacPhee, Philpott, and Barltrop, preceding paper.
[2] Burtner and Cusic, *J. Amer. Chem. Soc.*, 1943, **65**, 262; Lévin, Graham, and Kolloff, *J. Org. Chem.*, 1944, **9**, 380; Barltrop, *J.*, 1946, 958; Barltrop and his co-workers, Parts I and II, preceding papers.
[3] (*a*) Johnson, Petersen, and Schneider, *J. Amer. Chem. Soc.*, 1947, **69**, 76; (*b*) Johnson and Goldman, *ibid.*, 1945, **67**, 435.
[4] Cf. Gagnon and Charette, *Canad. J. Res.*, 1941, **19**, *B*, 287.
[5] Jeffreys, *Amer. Chem. J.*, 1899, **22**, 14.

readily obtainable from 2-diethylaminoethanol by reaction with thionyl chloride [6] followed by sodium hydroxide treatment which was conveniently done following Burtner's [7] directions. The chloroalkamine was condensed with *trans*-1-phenyl-2-indanylacetic acid in propan-2-ol by the method of Burtner and Cusic [2] and the required basic ester hydrochloride was obtained in 70% yield.

Experimental

cis- *and* trans-1-*Phenyl*-2-*indanylacetic Acid*.—3-Ethoxycarbonyl-4 : 4-diphenylbut-3-enoic acid was prepared from benzophenone and diethyl succinate by the method described by Johnson, Petersen, and Schneider.[3a] Cyclisation of this acid, followed by hydrolysis, gave 1-oxo-3-phenyl-2-indenylacetic acid.[3b] A solution of this acid (55 g.) in acetic acid (900 c.c.) was heated with amalgamated zinc (130 g.) to gentle reflux. Concentrated hydrochloric acid (1 l.) was slowly added during 1·5 hr. and the mixture was left to cool. Colourless crystals were deposited. The liquid was decanted, diluted with water, and thoroughly extracted with ether. The solid residue was also extracted with ether, and the united ether extracts were washed with water and treated with 5% sodium carbonate solution. Acidification of the alkaline extract gave colourless crystals, m. p. 105—140°, of 1-phenyl-2-indanylacetic acid (49·6 g., 95%), which were collected. Crystallisation from ethanol gave trans-1-*phenyl*-2-*indanylacetic acid* (22·9 g.), obtained on two further crystallisations from ethanol as plates, m. p. 157—158° (Found : C, 80·7; H, 6·5. $C_{17}H_{16}O_2$ requires C, 81·0; H, 6·4%). Addition of water to the ethanolic filtrate and storage overnight at 0° induced crystallisation of the cis-*acid* (18 g.) which, crystallised from toluene, had m. p. 111—115° (Found : C, 80·7; H, 6·6%).

trans-1-*Phenyl*-2-*indanylacetamide*.—A solution of *trans*-1-phenyl-2-indanylacetic acid in benzene was refluxed with an excess of phosphorus trichloride until hydrogen chloride ceased to be evolved. After filtration, most of the benzene was removed and the residue was poured with stirring into an excess of ammonia solution (*d* 0·88). Dilution with water completed precipitation and the *amide* was collected. After three crystallisations from ethanol it had m. p. 173—174° (Found : C, 81·5; H, 7·0; N, 5·1. $C_{17}H_{17}ON$ requires C, 81·3; H, 6·8; N, 5·6%).

trans-2-(N-*Methoxycarbonyl*)*aminomethyl*-1-*phenylindane*.—A solution of *trans*-1-phenyl-2-indanylacetamide (4·7 g.) in methanol (500 c.c.) was added to one from sodium (1·0 g.) and methanol (30 c.c.). Bromine (3·2 g.) was then added slowly with stirring, and the solution was heated at 60—70° for 15 min. Dilute acetic acid was added until the solution was just acid, and the methanol was removed. The solid residue was washed with hot water and triturated with hot ligroin (b. p. 80—100°). After filtering, the filtrate was concentrated and cooled to 0° ; the *urethane* (3·9 g.) was deposited. Three crystallisations from ethanol gave prisms, m. p. 103—104·5° (Found : C, 76·2; H, 6·7; N, 5·2. $C_{18}H_{19}O_2N$ requires C, 76·9; H, 6·8; N, 5·0%).

trans-2-*Aminomethyl*-1-*phenylindane Hydrochloride*.—The above urethane (2·9 g.) and a large excess of calcium hydroxide (11 g.) were dry distilled. *trans*-2-Aminomethyl-1-phenylindane, a yellow oil, was collected at 90—120°/0·15 mm. and was immediately dissolved in dry ether. On passage of dry hydrogen chloride through the ethereal solution, the *hydrochloride* (1 g.) was precipitated; this was collected and kept over solid sodium hydroxide for a day. Three crystallisations from ethanol containing a little ethyl acetate yielded plates, m. p. 312—313° (decomp.) (Found : C, 74·2; H, 7·2; N, 5·6. $C_{16}H_{17}N,HCl$ requires C, 74·0; H, 6·9; N, 5·4%).

trans-1-*Phenyl*-2-*indanylacetonitrile*.—A mixture of *trans*-1-phenyl-2-indanylacetamide (13 g.) and phosphoric oxide (4 g.) was dry distilled and the *nitrile* (5 g.), a colourless oil, was collected at 210—212°/10 mm. The compound was purified by washing it with alkali and distilling it, to a colourless oil, b. p. 200—200·5°/7 mm. (Found : C, 87·3; H, 6·2; N, 6·0. $C_{17}H_{15}N$ requires C, 87·5; H, 6·4; N, 6·0%).

trans-2-2'-*Aminoethyl*-1-*phenylindane Hydrochloride*.—*trans*-1-Phenyl-2-indanylacetonitrile (5 g.) in boiling ethanol (75 c.c.) was treated with sodium (11 g.), added in portions. When the reaction was complete, the mixture was allowed to cool, and water was added. The aqueous solution was extracted with ether, and the united ether extracts were treated with 10% hydrochloric acid. The acid solution was made alkaline by the addition of 5% aqueous sodium carbonate, and the liberated base was dissolved in ether. The *hydrochloride* was then obtained by the usual procedure and, crystallised from ethyl acetate, had m. p. 154—157° (Found : Cl, 12·9. $C_{17}H_{19}N,HCl$ requires Cl, 13·0%). The *toluene*-p-*sulphonyl derivative* separated from 5%

[6] Gilman and Shirley, *J. Amer. Chem. Soc.*, 1944, **66**, 888.
[7] Burtner, *ibid.*, 1949, **71**, 2378.

aqueous ethanol as plates, m. p. 135·5—136·5° (Found : N, 3·9; S, 8·2. $C_{24}H_{25}O_2NS$ requires N, 3·6; S, 8·2%).

2-Diethylaminoethyl trans-1-Phenyl-2-indanylacetate Hydrochloride.—2-Diethylaminoethyl chloride hydrochloride was prepared from 2-diethylaminoethanol as described by Gilman and Shirley [6] and converted into the free base.[7] The 2-diethylaminoethyl chloride (3·2 g) was added slowly with stirring to a hot solution of *trans*-1-phenyl-2-indanylacetic acid (6 g.) in propan-2-ol (40 c.c.), and the mixture was refluxed for 3 hr. The cooled solution was diluted with dry ether, and the precipitated *hydrochloride* (4·6 g., 70%) was collected, washed with ether, and dried. Crystallised thrice from ethyl acetate it had m. p. 127—130° (Found : Cl, 9·5. $C_{23}H_{29}O_2N,HCl$ requires Cl, 9·2%).

A pharmacological examination of these compounds was made by Smith, Kline and French Laboratories, Philadelphia, U.S.A. Compounds (VI) and (VII) were tested for analgesic activity in mice, after intraperitoneal administration, by the Eddy–Leimbach hot-plate procedure. Both compounds produced a significant elevation of the pain threshold, but their activities were rather lower than that of codeine. The effect of adrenaline in raising the arterial blood pressure was greatly augmented by previous administration of the ester (VI).

DYSON PERRINS LABORATORY, OXFORD. [*Received, August 26th*, 1955.]

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142. *Molecular Polarisability. The Apparent Anisotropy of Methane and Other Quasi-spherical Molecules.*

By (MRS.) C. G. LE FÈVRE, R. J. W. LE FÈVRE, and D. A. A. S. NARAYANA RAO.

By the formulæ ordinarily used, containing the terms $b_1 - b_2$, $b_2 - b_3$, and $b_3 - b_1$, tetrahedral molecules such as CH_4, CCl_4, CBr_4, etc., should not exhibit Kerr effects and should show zero depolarisation factors for light scattered by them. Actually, however, small values for both these properties have been observed. Past explanations of this anomaly have been qualitative. An *a priori* quantitative treatment, along the lines of that currently given for atomic polarisation, is here attempted. The expression derived for the molar Kerr constant of a structure CX_4 involves link moments, longitudinal and transverse polarisabilities a and b of bonds, stretching and bending force constants, effective charges on atoms, and the derivatives da/dr and db/dr (r being an internuclear distance). The new theory requires that the quantity $(da/dr - db/dr)$ should be a few powers of ten larger than da/dr (α being the mean polarisability). Data are presented showing that the electric double refraction of liquid carbon tetrachloride follows Kerr's law. The ${}_\infty({}_mK_2)$ and ${}_\infty P_2$ for carbon tetrabromide in carbon tetrachloride are recorded.

LE FÈVRE and LE FÈVRE [1] have adopted the definition (1) as the molar Kerr constant ${}_mK$ of a substance :

$$ {}_mK = 6\lambda nBM/(n^2 + 2)^2(\varepsilon + 2)^2 d \quad . \quad . \quad . \quad . \quad . \quad . \quad (1) $$

where n is the refractive index, M the molecular weight, ε the dielectric constant, and d the density. This property, except for an omitted numerical factor of 9, may be regarded as the difference between the molecular refractions per unit field taken perpendicular and parallel to an applied field E. By the theory ordinarily used for electric double refraction, B (and hence ${}_mK$) should be zero for quasi-spherical non-polar regular tetrahedral molecules of the type CR_4 (cf. relations and references given by Le Fèvre and Le Fèvre [1, 2]); in practice, however, small but definite values of B are observed, *e.g.*, for gaseous methane [3, 4] or liquid carbon tetrachloride (see Table 1). A connected phenomenon is that these

[1] Le Fèvre and Le Fèvre, *J.*, 1953, 4041.
[2] *Idem*, *J.*, 1954, 1577.
[3] Breazeale, *Phys. Rev.*, 1936, **49**, 625.
[4] Kuss and Stuart, *Phys. Z.*, 1941, **42**, 95.

supposedly isotropic substances give depolarisation factors ρ greater than the expected zero (cf. Cabannes [5]).

The problem posed by the apparent anisotropy of such molecules has not received much attention. Cabannes (ref. 5, pp. 133—134) comments on suggestions involving a square-based pyramidal configuration for CR_4, and on those depending on deformations during thermal agitation; he finally favours the hypothesis that atoms may have an intrinsic anisotropy measured by a depolarisation factor of 0·005. Bhagavantam [6] thinks that in the cases of silicon tetrachloride and tetrafluoride and carbon tetrachloride " the presence of an appreciable proportion of unsymmetrical isotopic molecules may be responsible for at least part of the observed depolarisation." [The unlikelihood of this is clear from the fact that although the relative abundance of ^{35}Cl to ^{37}Cl is 75 : 25, that of ^{1}H to ^{2}H is 5000 : 1; fluorine is 100% ^{19}F. The high values of ρ listed for silicon tetrachloride and tetrafluoride (ref. 6, p. 54) obviously require verification.] Quantum calculations cited by Beams [7]

FIG. 1.

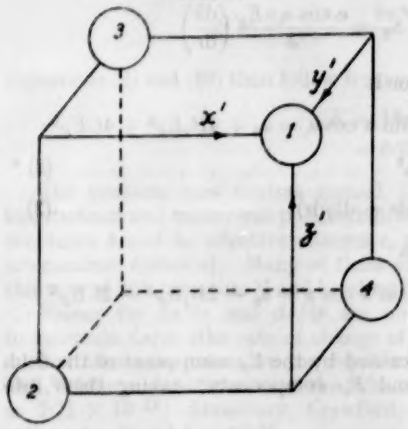
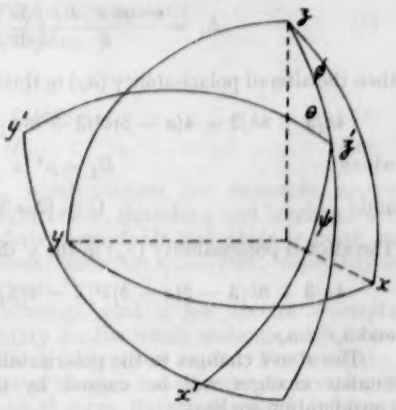


FIG. 2.



forecast the existence of a third small and temperature-invariant component of the quantity B, additional to the anisotropy and dipole terms provided by the Langevin–Born orientation theory.[8] Stuart [9] mentions the above proposals, together with others, *e.g.*, that in carbon tetrachloride, stannic chloride, etc., " schon bei Zimmertemperatur in ungefähr der Hälfte aller Molecüle angeregt sind, wodurch die Moleküle merklich anisotrop werden können," or that " die Nullpunktsbewegung der Kerne zu einer dauernden Störung der Symmetrie führen, so dass in jedem Augenblick eine geringe Anisotropie vorhanden wäre," so that, if the nuclear vibrations are slow relative to the frequency of light the molecules will scatter or behave in a Kerr cell as " verwackelte Tetraeder." Von Hippel [10] and Stuart [9] (*op. cit.*) note that anharmonicity of the oscillators responsible for electronic and atomic polarisation can produce a small temperature-insensitive effect, usually negligible except near an absorption line, although Neugebauer (quoted by Stuart ref. 9, p. 454) advances reasons why this " Voigtsches Glied " may be somewhat significant in the particular instance of methane.

While many of the above possibilities may be involved in the small Kerr constants, or depolarisation factors, reported for quasi-spherical molecules, the magnitudes of their

[5] Cabannes, " La Diffusion Moléculaire de la Lumière," Les Presses Universitaires de France, 1929, Tables 3, 9, 16, and 17.
[6] Bhagavantam, " Scattering of Light and Raman Effect," Andhra Univ., Waltair, 1940, pp. 53—56.
[7] Beams, *Rev. Modern Phys.*, 1932, **4**, 133.
[8] Van Vleck, " The Theory of Electric and Magnetic Susceptibilities," Oxford Univ. Press, 1932.
[9] Stuart, " Die Struktur des Freien Moleküls, " Springer, Berlin–Göttingen–Heidelberg, 1952, Sections 50, 57, and 62.
[10] Von Hippel, " Dielectrics and Waves," Wiley, New York, 1954, p. 264.

contributions cannot be usefully predicted quantitatively. Accordingly it seemed of interest to explore the results of assuming the types of distortion envisaged previously to explain atomic polarisation.[11, 12]

It is first necessary to compute the average polarisability per molecule along and at right angles to the applied field. In Figs. 1 and 2 let xyz be a space-fixed co-ordinate system whereon a static electric field E_0 is incident along the z axis. Let x', y', and z' be the principal axes of a tetrahedral molecule whose orientation with respect to xyz is given by θ, ϕ, and ψ. Consider the $E_{x'}$ component of the field : it distorts the molecule in such a way that the angle between the bond to atoms 1 and 4 decreases by 2δ (where $\delta = \mu \sin \alpha \,.\, E_{x'}/2k_\delta$) and that between the bonds 2 and 3 increases by the same amount (bending and stretching force constants are denoted by k_δ and k respectively). This distortion of the molecule leads to changes in its principal polarisabilities. Let a and b be the longitudinal and transverse polarisabilities of each of the four bonds and let $(\mathrm{d}a/\mathrm{d}r)$ and $(\mathrm{d}b/\mathrm{d}r)$ be the rates of change of a and b for bond elongation or contraction. Let

$$\Delta_1 = \frac{e \cos \alpha \,.\, E_{x'}}{k}\left(\frac{\mathrm{d}a}{\mathrm{d}r}\right) \quad \text{and} \quad \Delta_2 = \frac{e \cos \alpha \,.\, E_{x'}}{k}\left(\frac{\mathrm{d}b}{\mathrm{d}r}\right)$$

then the altered polarisability ($a_{x'}$) in the x' direction is

$$4a/3 + 8b/3 + 4(a - b)\delta^2/3 + 8(\Delta_1 - \Delta_2)\delta \sin \alpha \cos \alpha = a_0 + 4B_1E_{x'}^2 + 4CE_{x'}^2$$

where
$$B_1 = \mu^2 (a - b)/18k_\delta^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)\ *$$

and
$$C = (2\mu e/9kk_\delta)(\mathrm{d}a/\mathrm{d}r - \mathrm{d}b/\mathrm{d}r) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The altered polarisability ($a_{y'}$) in the y' direction is

$$4a/3 + 8b/3 - 2(a - b)\delta^2/3 - 4(\Delta_1 - \Delta_2)\delta \sin \alpha \cos \alpha = a_0 - 2B_1E_{x'}^2 - 2CE_{x'}^2$$

and $a_{z'} = a_{y'}$.

The above changes in the polarisabilities are caused by the $E_{x'}$ component of the field. Similar changes will be caused by the $E_{y'}$ and $E_{z'}$ components; taking them into consideration we have :

$$\begin{aligned}
\alpha_{x'} &= \alpha_0 + 4B_1E_{x'}^2 - 2B_1E_{y'}^2 - 2B_1E_{z'}^2 + 4CE_{x'}^2 - 2CE_{y'}^2 - 2CE_{z'}^2 \\
\alpha_{y'} &= \alpha_0 + 4B_1E_{y'}^2 - 2B_1E_{x'}^2 - 2B_1E_{z'}^2 + 4CE_{y'}^2 - 2CE_{x'}^2 - 2CE_{z'}^2 \\
\alpha_{z'} &= \alpha_0 + 4B_1E_{z'}^2 - 2B_1E_{x'}^2 - 2B_1E_{y'}^2 + 4CE_{z'}^2 - 2CE_{x'}^2 - 2CE_{y'}^2
\end{aligned}$$

To find the average moment induced per molecule per unit field along any of the space-fixed axes x, y, and z a random distribution of the molecules may be assumed, as the orientational effect of such small differences in the polarisabilities is negligible :

$$\begin{aligned}
\alpha_x &= \alpha_{x'}\overline{\cos^2 zx'} + \alpha_{y'}\overline{\cos^2 zy'} + \alpha_{z'}\overline{\cos^2 zz'} \\
&= \alpha_0 - 2(B_1 + C)E^2 + 6(B_1 + C)E^2\,[\overline{\cos^4 zx'} + \overline{[\cos^4 zy'} + \overline{\cos^4 zz']} \\
&= \alpha_0 + 8(B_1 + C)E^2/5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)
\end{aligned}$$

$$\begin{aligned}
\bar{\alpha}_x &= \alpha_{x'}\overline{\cos^2 xx'} + \alpha_{y'}\overline{\cos^2 xy'} + \alpha_{z'}\overline{\cos^2 xz'} \\
&= \alpha_0 - 2(B_1 + C)E^2 + 6(B_1 + C)E^2\,[\overline{\cos^2 zx' \cos^2 xx'} \\
&\qquad + \overline{\cos^2 zy' \cos^2 xy'} + \overline{\cos^2 zz' \cos^2 xz'}] \\
&= \alpha_0 - 4(B_1 + C)E^2/5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)
\end{aligned}$$

* B_1 is to be distinguished from B, the Kerr constant of a material measured as $(n_p - n_s)/\lambda E^2$, and which, *via* equation (1), gives ${}_mK$.

[11] Coop and Sutton, *J.*, 1938, 1269.
[12] Le Fèvre and Rao, *Austral. J. Chem.*, 1954, **7**, 135; 1955, **8**, 39.

Now, taking the Lorenz–Lorentz relation between refractive index and mean polarisability $(n_0^2 - 1)/(n_0^2 + 2) = 4\pi\nu\alpha/3$ (ν = number of molecules per c.c.) and differentiating, we have:

$$\frac{\Delta n_0}{n_0} = \frac{(n_0^2 - 1)(n_0^2 + 2)}{6n_0^2}\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\nu}{\nu}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Suitable insertions into equation (6) for $\Delta n_0 = n_p - n_0$ or $n_s - n_0$ with corresponding values of $\Delta\alpha$ from (4) and (5) lead to two further equations, which, by subtraction, give (7)

$$\frac{n_p - n_s}{n_0} = \frac{2(n_0^2 - 1)(n_0^2 + 2)(B_1 + C)E^2}{5n_0^2\alpha} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

By rearrangement of equation (7), introducing the wavelength λ, substituting $3M(n_0^2 - 1)/4\pi Nd(n_0^2 + 2)$ for α, and assuming the effective field to be $E(\varepsilon + 2)/3$, we obtain the Kerr constant, B, as

$$B = \frac{n_p - n_s}{\lambda E^2} = \frac{8\pi Nd(n^2 + 2)^2(\varepsilon + 2)^2(B_1 + C)}{135\lambda M n_0} \quad . \quad . \quad . \quad . \quad (8)$$

Equations (9) and (10) then follow from equation (1):

$$_mK = 16\pi N(B_1 + C)/45 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$= 6{\cdot}73 \times 10^{23}(B_1 + C) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The problem now centres around B_1 and C, which contain link moments, μ, the longitudinal and transverse polarisabilities a and b, of bonds, stretching and bending force constants k and k_δ, effective charges e, and the derivatives da/dr and db/dr (r being an internuclear distance). Many of these are, at present, uncertain quantities; especially is this true of link moments [12] and bending force constants.[13]

Values for da/dr and db/dr are unknown, although with a few species attempts to ascertain $d\alpha/dr$ (the rate of change of polarisability for the whole molecule with internuclear distance, taken at the equilibrium position) have been made. For methane, Bell,[14] from a consideration of the refractive indices of isotopic compounds, deduces $d\alpha/dr$ as $7{\cdot}71 \times 10^{-16}$; Stansbury, Crawford, and Welsh,[15] from Raman–Rayleigh intensity ratios, give it as $4{\cdot}1 \times 10^{-16}$.

It seemed at first possible that $d\alpha/dr$ might approach the order of $(da/dr - db/dr)$. However, by taking $7{\cdot}71 \times 10^{-16}$ as $(da/dr - db/dr)$, in conjunction with $\mu = 0{\cdot}31$ D, $e = 0{\cdot}55 \times 10^{-10}$ (from infrared data [12]), $a = 0{\cdot}081 \times 10^{-23}$, $b = 0{\cdot}057 \times 10^{-23}$ (Le Fèvre and Le Fèvre [2]), $k = 5{\cdot}04 \times 10^5$, and $k_\delta = 5{\cdot}51 \times 10^{-12}$ (cf. Herzberg [16]), the molar Kerr constant calculated *via* equation (10) for methane is only 1×10^{-15}, *i.e.*, some 200—300 times smaller than the values expected from the recorded observations on highly compressed methane by Breazeale [3] or Kuss and Stuart.[4]

For carbon tetrachloride Chien and Bender [17] consider $d\alpha/dr$ to be *ca.* 4×10^{-16}. Noting that this is not far from $a/r + b/r$, and because no estimate of $d\alpha/dr$ for carbon tetrabromide is available, we have used a and b as given earlier,[2] together with $r_{CCl} = 1{\cdot}755$ Å and $r_{CBr} = 1{\cdot}94$ Å, plus the assumptions that μ_{C-Cl} or μ_{C-Br} are both *ca.* 1·8 D, that $e = \mu/r$, and that the force constants reported by Heath and Linnett [13b] are applicable, to produce $_mK_{calc.} = 0{\cdot}053 \times 10^{-12}$ for carbon tetrachloride and $0{\cdot}11 \times 10^{-12}$ for the tetrabromide. As with methane, but to a lesser degree, these are below the observed values.

Either, therefore, our model and argument leading to equations (9) and (10) are incorrect, or it is wrong to expect $(da/dr - db/dr)$ to have the same order of magnitude as $d\alpha/dr$. It is conceivable that the latter alternative is the case: consider a total symmetric

[12] (*a*) Linnett, *Quart. Rev.*, 1947, **1**, 73; (*b*) Heath and Linnett, *Trans. Faraday Soc.*, 1948, **54**, 561.
[14] Bell, *ibid.*, 1942, **38**, 422.
[15] Stansbury, Crawford, and Welsh, *Canad. J. Phys.*, 1953, **31**, 954.
[16] Herzberg, "Infrared and Raman Spectra," Van Nostrand, New York, 1945.
[17] Chien and Bender, *J. Chem. Phys.*, 1947, **15**, 376.

vibration of, *e.g.*, methane. Let each bond have an extension dr. Then, α being the mean polarisability,

$$\alpha + \mathrm{d}\alpha = \frac{4}{3}\left(a + \frac{\mathrm{d}a}{\mathrm{d}r}\,.\,\mathrm{d}r\right) + \frac{8}{3}\left(b + \frac{\mathrm{d}b}{\mathrm{d}r}\,.\,\mathrm{d}r\right)$$

whence, since $(4a + 8b)/3 = \alpha$, $\mathrm{d}\alpha/\mathrm{d}r = \frac{4}{3}\left(\frac{\mathrm{d}a}{\mathrm{d}r} + 2\frac{\mathrm{d}b}{\mathrm{d}r}\right)$. In other words, were $\mathrm{d}b/\mathrm{d}r$ to be nearly $-0{\cdot}5\mathrm{d}a/\mathrm{d}r$, admittedly a speculative suggestion, then $\mathrm{d}\alpha/\mathrm{d}r$ might well be a few powers of ten smaller than either $\mathrm{d}a/\mathrm{d}r$ or $\mathrm{d}b/\mathrm{d}r$. It is relevant that, with the force constants and other data cited above, the quantities $(\mathrm{d}a/\mathrm{d}r - \mathrm{d}b/\mathrm{d}r)$ need only to be $4{\cdot}2 \times 10^{-13}$, $1{\cdot}5 \times 10^{-14}$, and $7{\cdot}2 \times 10^{-14}$ to give, *via* equation (10), the observed molar Kerr constants respectively for methane, carbon tetrachloride, and carbon tetrabromide (*viz.*, $0{\cdot}395 \times 10^{-12}$, $1{\cdot}14 \times 10^{-12}$, and $7{\cdot}3 \times 10^{-12}$). On such a basis $\mathrm{d}a/\mathrm{d}r$ and $\mathrm{d}b/\mathrm{d}r$ would be, for the C–H link, $2{\cdot}8 \times 10^{-13}$ and $-1{\cdot}4 \times 10^{-13}$, and for the C–Cl link, $1{\cdot}0 \times 10^{-14}$ and $-0{\cdot}5 \times 10^{-14}$. Unfortunately no method is known to us whereby these predictions could be checked by experiment.

Practical Importance of Equation (9).—The molar Kerr constant is usually analysed thus:

$$_mK = 2\pi N(\theta_1 + \theta_2)/9 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

(cf. refs. 1 and 2 for expansions of θ_1 and θ_2, the anisotropy and dipole terms respectively). Clearly the right-hand side of (9) amounts to an addition to equation (11) (within the parentheses) of $\theta_3 = 8(B_1 + C)/5$. θ_3 differs from θ_1 or θ_2 in being temperature-invariant.

So far as the practical usefulness of the Kerr effect is concerned, θ_3 will only be significant for near-isotropic molecules for which $_mK_{\mathrm{obs.}}$ is small and possibly therefore composed relatively considerably of contributions containing θ_3. In such cases molecular ellipsoids computed from $_mK_{\mathrm{obs.}}$ would represent the structure as being more anisotropic than it really is.

This type of error may explain why a and b for the carbon–carbon link (cf. ref. 2 for references) have been reported as uniquely (compared with other bonds) dissimilar, a/b ranging with different authors from 20 to 94. Various considerations suggest [18, 19] that the correct $a : b$ ratio is between 2 and 4. The earlier estimates were based essentially on measurements of the Kerr constant of ethane [3] and involved the setting-up of expressions, for the b_1 and b_3 found, containing a and b for C–C and C–H.

We now note that if from the value of $_mK$ for ethane we deduct the amount which could be regarded as approximating to the appropriate θ_3 (*viz.*, subtracting from $_mK_{\mathrm{C_2H_6}}$ twice $_mK_{\mathrm{CH_4}}$) and calculate from the residue, taken as the " true " θ_1, a new b_1 and b_3, then a and b for the carbon–carbon bond emerge in the ratio $a : b$ as 3·93 : 1.

Finally it may be remarked that the molecular distortions assumed in this paper may well be part of the mechanism operative in the phenomenon of hyperpolarisability discussed by Coulson, Maccoll, and Sutton.[20]

Experimental

Applicability of Kerr's Law to Carbon Tetrachloride.—A search through the literature disclosed that Kerr's law, stating [21] that the magnitude of the double refraction is proportional to the square of the strength of the electric field applied, has never been tested on a material having tetrahedral quasispherical molecules. Anisotropically polarisable substances, notably carbon disulphide,[22] have, however, received extensive attention, and been found to obey the law accurately so that the omission of, *e.g.*, the readily available carbon tetrachloride arouses the suspicion that its weak electric double refraction may not have the normal dependence on E^2. Such a doubt required to be removed at the beginning of the present work.

Apparatus and techniques [1, 2] and carbon tetrachloride [2] as described earlier being used, retardations δ were observed as listed in Table 1. Constancy is obtained only with the ratio

[18] Bunn and Daubeny, *Trans. Faraday Soc.*, 1954, **50**, 1173.
[19] Le Fèvre and Le Fèvre, *Chem. and Ind.*, 1955, 506, 1121.
[20] Coulson, Maccoll, and Sutton, *Trans. Faraday Soc.*, 1952, **48**, 106.
[21] Kerr, *Phil. Mag.*, 1880, **9**, 157; 1882, **13**, 153, 248.
[22] Chaumont, *Ann. Physique*, 1916, **5**, 17; Beams, *Phys. Rev.*, 1931, **37**, 781; Hootman, *ibid.*, 1933, **43**, 749.

TABLE 1. *Electric double refraction of carbon tetrachloride at 25° for light of λ = 5893 Å.*

δ (minutes)	*E* (kv applied)	δ/E	δ/E^2	10^7B	δ/E^3
8·5	5	1·70	0·340	0·072	0·68
12	6	2·00	0·333	0·071	$0·55_5$
16	7	$2·28_5$	0·327	0·070	0·47
21	8	$2·62_5$	0·328	0·070	0·41
26·5	9	2·94	0·327	0·070	0·36
33	10	3·30	0·330	0·070	0·33
40·5	11	3·68	$0·334_5$	0·071	0·30
47·5	12	3·96	0·330	0·070	$0·27_5$

TABLE 2. *Observations on carbon tetrabromide in carbon tetrachloride at 20°.**

10^5w_2	10^7B_{12}	$(n_D')_{12}$	$(d_4')_{12}$	$(\varepsilon')_{12}$
0	0·072	1·4604	1·5940	2·2360
1881	0·074	—	—	—
2014	0·076	1·4621	1·6105	—
3332	0·077	—	—	—
3683	0·083	1·4637	1·6239	2·2454
6303	0·085	1·4661	1·6463	2·2525
6516	0·085	1·4662	1·6475	2·2536
8814	0·086	—	—	—

Whence $\Sigma(w_2 \cdot \Delta B)/\Sigma w_2^2 = 0·187$, $\Sigma\Delta n/\Sigma w_2 = 0·089$, $\Sigma\Delta d/\Sigma w_2 = 0·822$, $\Sigma\Delta\varepsilon/\Sigma w_2 = 0·264$.

* For explanations of symbols and methods of calculation used see refs. 1 and 2.

δ/E^3. Use of the dimensions of the plates and their separation gives the " Kerr constants " *B*. The behaviour of carbon tetrachloride is therefore externally orthodox.

The Molar Kerr Constant of Carbon Tetrabromide.—From the observations included in Table 2 the following quantities emerge: ${}_\infty P_2 = 38·6$ c.c., $\mu = ca.\ 0$ D., ${}_\infty({}_mK_2) = 7·30 \times 10^{-12}$. No previous determination of either the polarisation or the Kerr constant of carbon tetrabromide is on record.

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143. *New Thiosemicarbazones and 4-Oxo-Δ²-thiazolin-2-ylhydrazones.*

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A large number of thiosemicarbazones and 4-oxo-Δ²-thiazolin-2-ylhydrazones, many derived from benzyloxybenzaldehydes, have been prepared for biological testing.

OWING to the varied medical potentialities of thiosemicarbazones,[1] and to the fact that some inhibit slightly the growth of Sarcoma 180 in mice (personal communication from Dr. Chester Stock, Sloan-Kettering Institute, New York) (annexed Table), the new

Thiosemicarbazone of:	Inhibitory dose (mg./kg./day)
p-(4-Methylbenzyloxy)benzaldehyde	10
p-(4-Chlorobenzyloxy)benzaldehyde	30
p-(4-Bromobenzyloxy)benzaldehyde	35
4-Methoxy-1-naphthaldehyde	250
4-(3-Phenylpropyloxy)benzaldehyde	10

thiosemicarbazones listed in Table 1 have been prepared. Table 2 records the new benzyloxybenzaldehydes prepared as intermediates. Some 4-oxo-Δ²-thiazolin-2-ylhydrazones

[1] See, *inter al.*, Hoggarth *et al.*, *Brit. J. Pharmacol.*, 1949, **4**, 248; Donovick *et al.*, *J. Bacteriol.*, 1950, **59**, 667; Bavin *et al.*, *J. Pharm. and Pharmacol.*, 1950, **2**, 764; Buu-Hoï *et al.*, *J.*, 1952, 4590; 1953, 547; 1955, 1581; Domagk, *Naturwiss.*, 1946, **33**, 315; Behnisch *et al.*, *Angew. Chem.*, 1948, **60**, 113; Perry, *J. Amer. Chem. Soc.*, 1954, **76**, 3591; Buu-Hoï, *Internat. J. Leprosy*, 1954, **22**, 16; *Bull. Calcutta School Trop. Med.*, 1955, **3**, 133; Buu-Hoï *et al.*, *J. Org. Chem.*, 1953, **18**, 121.

TABLE 1. *Thiosemicarbazones.*[a]

Aldehyde or ketone	M. p.	Formula	Found (%) C	Found (%) H	Reqd. (%) C	Reqd. (%) H
p-Fluorobenzaldehyde	180°	$C_8H_8N_3SF$	48·5	4·0	48·7	4·1
4-Methoxy-3-methylbenzaldehyde	194	$C_{10}H_{13}ON_3S$	53·6	6·0	53·8	5·8
4-Methoxy-2-methylbenzaldehyde	213	$C_{10}H_{13}ON_3S$	53·6	5·7		
2-Methoxy-5-methylbenzaldehyde	212	$C_{10}H_{13}ON_3S$	54·0	5·7		
p-(2-Chlorobenzyloxy)benzaldehyde	167	$C_{15}H_{14}ON_3SCl$	56·0	4·5	56·3	4·4
p-(2 : 4-Dichlorobenzyloxy)benzaldehyde	192	$C_{15}H_{13}ON_3SCl_2$	50·7	4·0	50·8	3·7
m-Benzyloxybenzaldehyde	157	$C_{15}H_{15}ON_3S$	63·0	5·1	63·2	5·3
m-(4-Chlorobenzyloxy)benzaldehyde	160	$C_{15}H_{14}ON_3SCl$	56·0	4·1	56·3	4·4
m-(4-Bromobenzyloxy)benzaldehyde	165	$C_{15}H_{14}ON_3SBr$	49·2	4·1	49·5	3·8
m-(4-Methylbenzyloxy)benzaldehyde	156	$C_{16}H_{17}ON_3S$	64·1	5·9	64·2	5·7
o-Benzyloxybenzaldehyde	160	$C_{15}H_{15}ON_3S$	63·3	5·2	63·2	5·3
o-(2-Chlorobenzyloxy)benzaldehyde	168	$C_{15}H_{14}ON_3SCl$	56·0	4·2	56·3	4·4
o-(4-Chlorobenzyloxy)benzaldehyde	225	$C_{15}H_{14}ON_3SCl$	56·1	4·1		
o-(2 : 4-Dichlorobenzyloxy)benzaldehyde	237	$C_{15}H_{13}ON_3SCl_2$	50·7	4·0	50·8	3·7
o-(4-Methylbenzyloxy)benzaldehyde	198	$C_{16}H_{17}ON_3S$	64·5	5·5	64·2	5·7
o-(4-Bromobenzyloxy)benzaldehyde	189	$C_{15}H_{14}ON_3SBr$	49·2	3·7	49·5	3·8
3-Formylpyrene[b]	270	$C_{18}H_{12}N_2S$	71·2	4·5	71·3	4·3
2-Benzyloxy-1-naphthaldehyde	210	$C_{19}H_{17}ON_3S$	68·0	5·3	68·1	5·1
3-Nitropropiophenone	199	$C_{10}H_{12}O_3N_4S$	47·5	4·8	47·6	4·8
4-Methylpropiophenone	146	$C_{11}H_{15}N_3S$	59·4	6·8	59·7	6·8
4-Bromopropiophenone	169	$C_{10}H_{12}N_3SBr$	41·8	4·1	42·0	4·2
3-Methyl-4-methylthiopropiophenone	152	$C_{12}H_{17}N_3S_2$	53·6	6·2	53·9	6·4
2-Propionylthiophen	128	$C_8H_{11}N_3S_2$	44·9	5·0	45·1	5·2
4-*isol*Propylpropiophenone	123	$C_{13}H_{19}N_3S$	62·8	7·5	62·7	7·6
4-Methyl-1-propionylnaphthalene	174	$C_{15}H_{17}N_3S$	66·1	6·5	66·4	6·3
2 : 4-Dimethoxyacetophenone	170	$C_{11}H_{15}O_3N_3S$	52·0	5·7	52·2	5·9
2 : 4-Dimethylacetophenone	158	$C_{11}H_{15}N_3S$	59·4	6·9	59·7	6·8
4-Iodoacetophenone	210	$C_9H_{10}N_3SI$	34·1	3·3	33·9	3·1
3-Bromo-4-methoxyacetophenone	208	$C_{10}H_{12}ON_3SBr$	39·5	4·0	39·7	4·0
2-Acetylphenanthrene	217	$C_{17}H_{13}N_3S$	69·8	5·0	69·6	5·1
3-Acetylphenanthrene	176	$C_{17}H_{13}N_3S$	69·5	5·2		
2-*n*-Decanoylfluorene	118	$C_{24}H_{31}N_3S$	73·0	8·0	73·3	7·9
6-Propionyltetralin	133	$C_{14}H_{19}N_3S$	64·4	7·2	64·4	7·3
Myristophenone	81	$C_{21}H_{35}N_3S$	70·1	9·6	69·8	9·7
2-Methoxy-6-phenylacetylnaphthalene	167	$C_{20}H_{19}ON_3S$	69·0	5·1	68·8	5·4
4-Phenoxyacetophenone	149	$C_{15}H_{15}ON_3S$	63·1	5·5	63·2	5·3
4-Phenylthiopropiophenone	129	$C_{16}H_{17}N_3S_2$	60·8	5·5	61·0	5·4
3-Acetyl-9-ethylcarbazole	203	$C_{17}H_{18}N_4S$	65·7	6·1	65·8	5·8
Methyl *cyclo*propyl ketone	107	$C_5H_{11}N_3S$	45·9	7·3	45·9	7·0
Octan-2-one	70	$C_9H_{19}N_3S$	53·9	9·5	53·7	9·5
Undecan-2-one	93	$C_{12}H_{25}N_3S$	59·0	10·1	59·2	10·3
5-Bromoisatin[c]	223	$C_9H_7ON_4SBr$	36·3	2·5	36·1	2·3

[a] The high-melting thiosemicarbazones generally decomposed at the m. p. [b] Bright yellow prisms. [c] Orange-yellow needles from acetic acid.

TABLE 2. *Benzyloxybenzaldehydes.*

	M. p.	B. p./mm.	Formula	Found (%) C	Found (%) H	Reqd. (%) C	Reqd. (%) H
p-(2-Chlorobenzyloxy)benzaldehyde	50°	252°/25	$C_{14}H_{11}O_2Cl$	68·5	4·5	68·2	4·5
p-(2 : 4-Dichlorobenzyloxy)benzaldehyde	102	282/30	$C_{14}H_{10}O_2Cl_2$	59·6	3·6	59·8	3·6
m-Benzyloxybenzaldehyde	49	225/25	$C_{14}H_{12}O_2$	79·2	5·8	79·2	5·7
m-(4-Chlorobenzyloxy)benzaldehyde	[a]	248/18	$C_{14}H_{11}O_2Cl$	68·3	4·6	68·2	4·5
m-(4-Bromobenzyloxy)benzaldehyde	[b]	254/18	$C_{14}H_{11}O_2Br$	57·8	4·1	57·7	3·8
m-(4-Methylbenzyloxy)benzaldehyde	[c]	240/22	$C_{15}H_{14}O_2$	79·8	6·3	79·6	6·2
o-(2-Chlorobenzyloxy)benzaldehyde	70	246/25	$C_{14}H_{11}O_2Cl$	68·1	4·5	68·2	4·5
o-(4-Chlorobenzyloxy)benzaldehyde	82	—	$C_{14}H_{11}O_2Cl$	68·0	4·8	68·2	4·5
o-(4-Bromobenzyloxy)benzaldehyde	68	258/18	$C_{14}H_{11}O_2Br$	58·0	3·9	57·7	3·8
o-(2 : 4-Dichlorobenzyloxy)benzaldehyde	135	—	$C_{14}H_{10}O_2Cl_2$	60·1	3·9	59·8	3·6
o-(4-Methylbenzyloxy)benzaldehyde	[d]	228/13	$C_{15}H_{14}O_2$	79·8	6·3	79·6	6·2

[a] n_D^{17} 1·6032. [b] $n_D^{20\cdot5}$ 1·6109. [c] n_D^{17} 1·5904. [d] n_D^{15} 1·5922.

are tuberculostatic *in vivo*;[2] several new ones are listed in Table 3; they include the 4-oxo-Δ^2-thiazolin-2-ylhydrazones of 2-, 3-, and 4-formylpyridine which yield highly tuberculostatic thiosemicarbazones.[3]

[2] Ratsimamanga *et al.*, *Bull. Soc. Chim. biol.*, 1952, **146**, 354.

[3] Levaditi, Girard, Vaisman, and Ray, *Compt. rend.*, 1950, **231**, 1174; Gardner, Smith, Wenis, and Lee, *J. Org. Chem.*, 1951, **16**, 1121.

TABLE 3. 4-*Oxo*-5-R-Δ^2-*thiazolin*-2-*ylhydrazones*.

Prepd. from :	R	M. p.	Formula	Found (%) C	Found (%) H	Reqd. (%) C	Reqd. (%) H
p-Fluorobenzaldehyde	H	291°	$C_{10}H_8ON_3SF$	50·5	3·2	50·6	3·4
p-Fluorobenzaldehyde	Et	230	$C_{12}H_{12}ON_3SF$	54·0	4·8	54·3	4·5
p-Fluorobenzaldehyde	Pr^i	205	$C_{13}H_{14}ON_3SF$	56·0	5·1	55·9	5·0
p-Fluorobenzaldehyde	Pr^n	208	$C_{13}H_{14}ON_3SF$	56·1	5·3	55·9	5·0
p-Fluorobenzaldehyde	Bu^n	220	$C_{14}H_{16}ON_3SF$	57·5	5·6	57·3	5·5
p-Fluorobenzaldehyde	Bu^i·CH$_2$	201	$C_{15}H_{18}ON_3SF$	58·3	6·0	58·6	5·9
p-Fluorobenzaldehyde	*n*-$C_{11}H_{23}$	158	$C_{21}H_{34}ON_3SF$	66·6	8·4	66·5	8·3
p-Fluorobenzaldehyde	*n*-$C_{16}H_{33}$	150	$C_{26}H_{44}ON_3SF$	67·7	9·0	67·7	8·7
4-Methoxy-3-methylbenzaldehyde	H	252	$C_{12}H_{13}O_2N_3S$	54·5	4·7	54·8	4·9
4-Methoxy-2-methylbenzaldehyde	H	262	$C_{12}H_{13}O_2N_3S$	54·7	5·0	54·8	4·9
2-Methoxy-5-methylbenzaldehyde	H	246	$C_{12}H_{13}O_2N_3S$	54·6	4·8	54·8	4·9
p-(2-Chlorobenzyloxy)benzaldehyde	H	236	$C_{17}H_{14}O_2N_3SCl$	56·4	4·1	56·7	3·9
p-(2 : 4-Dichlorobenzyloxy)benzaldehyde	H	253	$C_{17}H_{13}O_2N_3SCl_2$	52·0	3·3	51·8	3·3
m-Benzyloxybenzaldehyde	H	199	$C_{17}H_{15}O_2N_3S$	62·9	4·8	62·8	4·6
m-(4-Chlorobenzyloxy)benzaldehyde	H	220	$C_{17}H_{14}O_2N_3SCl$	56·5	3·8	56·7	3·9
m-(4-Bromobenzyloxy)benzaldehyde	H	228	$C_{17}H_{14}O_2N_3SBr$	50·2	3·8	50·5	3·5
m-(4-Methylbenzyloxybenzaldehyde	H	183	$C_{18}H_{17}O_2N_3S$	63·5	5·0	63·7	5·0
o-Benzyloxybenzaldehyde	H	212	$C_{17}H_{15}O_2N_3S$	62·8	4·4	62·8	4·6
o-(4-Chlorobenzyloxy)benzaldehyde	H	204	$C_{17}H_{14}O_2N_3SCl$	56·4	3·9	56·7	3·9
o-(4-Bromobenzyloxy)benzaldehyde	H	204	$C_{17}H_{14}O_2N_3SBr$	50·3	3·3	50·5	3·5
o-(2: 4-Dichlorobenzyloxy)benzaldehyde	H	200	$C_{17}H_{13}O_2N_3SCl_2$	51·5	3·2	51·8	3·3
o-(2-Chlorobenzyloxy)benzaldehyde	H	219	$C_{17}H_{14}O_2N_3SCl$	56·9	4·1	56·7	3·9
o-(4-Methylbenzyloxy)benzaldehyde	H	212	$C_{18}H_{17}O_2N_3S$	63·8	5·2	63·7	5·0
p-Anisaldehyde	Et	181	$C_{12}H_{15}O_2N_3S$	56·0	5·2	56·3	5·4
p-Anisaldehyde	Bu^n	160	$C_{14}H_{19}O_2N_3S$	59·3	6·0	59·0	6·2
p-Anisaldehyde	*n*-$C_{12}H_{25}$	128	$C_{22}H_{35}O_2N_3S$	66·3	8·5	66·2	8·4
p-Anisaldehyde	*n*-$C_{14}H_{29}$	116	$C_{24}H_{39}O_2N_3S$	67·7	8·9	67·4	8·8
p-Anisaldehyde	*n*-$C_{16}H_{33}$	108	$C_{26}H_{43}O_2N_3S$	68·6	9·4	68·5	9·1
p-Acetamidobenzaldehyde	H	342—345	$C_{12}H_{12}O_2N_4S$	51·8	4·3	52·2	4·3
p-Acetamidobenzaldehyde	Bu^n	218	$C_{16}H_{20}O_2N_4S$	57·5	6·1	57·8	6·0
p-Dimethylaminobenzaldehyde	H	251	$C_{12}H_{14}ON_4S$	55·0	5·0	55·0	5·3
p-Dimethylaminobenzaldehyde	Et	223	$C_{14}H_{18}ON_4S$	57·6	6·0	57·9	6·2
p-Dimethylaminobenzaldehyde	Bu^n	214	$C_{16}H_{22}ON_4S$	60·1	7·0	60·4	6·9
p-Dimethylaminobenzaldehyde	*n*-$C_{12}H_{25}$	153	$C_{26}H_{38}ON_4S$	67·2	9·0	67·0	8·8
p-Dimethylaminobenzaldehyde	*n*-$C_{14}H_{29}$	150	$C_{28}H_{42}ON_4S$	68·2	9·5	68·1	9·2
p-Dimethylaminobenzaldehyde	*n*-$C_{16}H_{33}$	145	$C_{30}H_{46}ON_4S$	69·4	9·6	69·1	9·5
Cinnamaldehyde	Et	232	$C_{14}H_{15}ON_3S$	61·2	5·3	61·5	5·5
Cinnamaldehyde	Bu^n	203	$C_{16}H_{19}ON_3S$	63·8	6·0	63·8	6·3
3-Formylpyrene	H	>310	$C_{28}H_{15}ON_3S$	69·7	3·6	70·0	3·8
3-Acetyl-9-ethylcarbazole	H	254	$C_{18}H_{18}ON_4S$	65·0	5·1	65·1	5·1
2-Acetylphenanthrene	H	>320	$C_{18}H_{16}ON_3S$	68·8	4·4	68·5	4·5
3-Acetylphenanthrene	H	>320	$C_{18}H_{16}ON_3S$	68·6	4·6	68·5	4·5
2-Propiothienone	H	245	$C_{10}H_{11}ON_3S_2$	47·6	4·2	47·4	4·3
2 : 4-Dimethoxyacetophenone	H	220	$C_{13}H_{15}O_3N_3S$	53·0	5·3	53·2	5·1
4-Bromopropiophenone	H	208	$C_{12}H_{14}ON_3SBr$	44·4	3·6	44·2	3·7
3-Bromo-4-methoxyacetophenone	H	239	$C_{12}H_{12}O_2N_3SBr$	42·4	3·5	42·1	3·5
4-Iodoacetophenone	H	247	$C_{11}H_{10}ON_3SI$	36·4	2·7	36·7	2·8
2 : 4-Dimethylacetophenone	H	237	$C_{12}H_{15}ON_3S$	59·5	5·5	59·8	5·7
4-Methylpropiophenone	H	221	$C_{12}H_{15}ON_3S$	59·4	5·8	59·8	5·7
4-Methyl-1-propionaphthone	H	238	$C_{13}H_{17}ON_3S$	65·5	5·8	65·6	5·5
2-Methoxy-6-phenylacetylnaphthalene	H	253	$C_{22}H_{19}O_2N_3S$	67·6	4·8	67·9	4·9
Citral	H	178	$C_{13}H_{19}ON_3S$	59·0	7·0	58·9	7·2
Citral	Et	149	$C_{15}H_{23}ON_3S$	61·2	7·8	61·4	7·8
Citral	Bu^n	147	$C_{17}H_{27}ON_3S$	63·3	8·4	63·6	8·4
Octan-2-one	H	122	$C_{11}H_{19}ON_3S$	54·5	7·7	54·8	7·9
Octan-2-one	Bu^n	89	$C_{15}H_{27}ON_3S$	60·5	9·0	60·6	9·1
Undecan-2-one	H	147	$C_{14}H_{25}ON_3S$	59·5	9·0	59·4	8·8
Undecan-2-one	Bu^n	84	$C_{18}H_{33}ON_3S$	63·9	9·6	63·7	9·7
2-Formylpyridine	H	264	$C_9H_8ON_4S$	N, 25·3		N, 25·5	
3-Formylpyridine	H	278	$C_9H_8ON_4S$	N, 25·1		N, 25·5	
4-Formylpyridine	H	271	$C_9H_8ON_4S$	N, 25·2		N, 25·5	

The tuberculostatic activities varied widely (determined on *Mycobacterium tuberculosis* var. *bovis*, strain B.C.G., in Dubos–Davis Tween–albumin medium). The most active compounds are reported in Table 4. Active ketone thiosemicarbazones were often structurally related to active aldehyde thiosemicarbazones. Some activity was also

shown by 3-mercapto-5 : 6-dimethyl-1 : 2 : 4-triazine, prepared by condensation of thiosemicarbazide with diacetyl. 4-Oxo-Δ²-thiazolin-2-ylhydrazones were considerably less active than their active parent thiosemicarbazones. Most thiosemicarbazones rapidly

caused fatty degeneration and hæmorrhage in the liver of rats and mice, the 4-oxo-Δ²-thiazolin-2-ylhydrazones less so. In tests for antithyroid properties in rats, 3-mercapto-5 : 6-dimethyl-1 : 2 : 4-triazine had little effect compared with thiouracil at similar dose.

TABLE 4. *Thiosemicarbazones showing marked tuberculostatic activity* in vitro.[a,b]

Active at 1 : 10^5	Active at 1 : 10^6
9-Ethyl-3-formyl-6-nitrocarbazole	6-Bromo-9-ethyl-3-formylcarbazole
9-Formylanthracene	*p*-(2-Chlorobenzyloxy)benzaldehyde
3-Formylpyrene	Cinnamaldehyde
Methyl *cyclo*propyl ketone	*p*-(2 : 4-Dichlorobenzyloxy)benzaldehyde
7-Phenylheptatrienal	4-Methoxy-3-methylbenzaldehyde
5-Phenylpentadienal	
3-Phenylpropanol	Active at 1 : 10—10^7
4-*n*-Tetradecanoylbenzene	3-Acetyl-9-ethylcarbazole
Undecan-2-one	*p*-Ethoxybenzaldehyde
	Piperonaldehyde
Active at 1 : 10^5—10^6	
5-Chloro-2-cinnamyloxybenzaldehyde	Active at 1 : 10^7
4-Methoxyacetophenone	3-Formylphenothiazine

[a] Readings taken after 3 weeks' incubation. [b] The corresponding 4-oxo-Δ²-thiazolin-2-ylhydrazones did not show tuberculostatic activity at concentrations lower than 1 : 10^4.

EXPERIMENTAL

Preparation of Thiosemicarbazones.—Thiosemicarbazones derived from aldehydes were prepared in 80—95% yield in the minimum volume of boiling ethanol and recrystallised from ethanol, benzene, or acetic acid. Thiosemicarbazones derived from ketones were prepared, generally in lower yield, in boiling alcohol containing a drop of acetic acid (30 min.).

Preparation of 4-Oxo-Δ²-thiazolin-2-ylhydrazones[4] of Aldehydes and Ketones.—A solution of the thiosemicarbazone (1 mol.) and chloroacetic acid or the appropriate α-bromo-acid (1 mol.) was refluxed with sodium acetate (1·5 mol.) for 1 hr. The resulting 4-oxo-Δ²-thiazolin-2-ylhydrazone was recrystallised from ethanol or acetic acid.

3-Mercapto-5 : 6-dimethyl-1 : 2 : 4-triazine.—A solution of diacetyl (8·6 g.) and thiosemicarbazide (9 g.) in ethanol was boiled for a few minutes, and the orange-yellow precipitate was collected after cooling, and recrystallised from ethanol. The *triazine* (12 g.) was soluble in aqueous alkali and decomposed at 191° (Found: N, 29·3. $C_5H_7N_3S$ requires N, 29·8%). It was tuberculostatic at concentrations of 1 : 10^5 to 10^6.

Preparation of Benzyloxybenzaldehydes.—Equimolecular amounts of the hydroxyaldehyde and the appropriate benzyl chloride were condensed in ethanolic sodium hydroxide. The products were distilled *in vacuo* and recrystallised from ligroin or methanol. *2-Benzyloxy-1-naphthaldehyde* crystallised as yellowish needles, m. p. 126°, from ethanol (Found: C, 82·1; H, 5·5. $C_{18}H_{14}O_2$ requires C, 82·4; H, 5·3%); its *isonicotinoylhydrazone* formed yellow prisms, m. p. 239°, from ethanol (Found: N, 11·2. $C_{24}H_{19}O_2N_3$ requires N, 11·0%), its *nicotinoylhydrazone*, shiny yellow leaflets, m. p. 210°, from ethanol (Found: N, 10·9%), and its *5-chlorosalicyloylhydrazone*, colourless needles, m. p. 202°, from ethanol (Found: N, 6·7. $C_{25}H_{19}O_3N_3Cl$ requires N, 6·5%).

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[4] Wilson *et al.*, *J.*, 1922, **121**, 876; 1923, **123**, 799; 1926, 253; Chabrier *et al.*, *Bull. Soc. chim. France*, 1947, **14**, 797; 1950, **17**, 48.

144. *Stages in Oxidations of Organic Compounds by Potassium Permanganate. Part VII.* Characteristic Features of Oxidations involving the Manganate, MnO_4^{2-}, and Hypomanganate, MnO_4^{3-}, Anions.*

By J. S. F. Pode and William A. Waters.

Reactions of organic compounds with alkaline solutions of MnO_4^{2-} and MnO_4^{3-} have been surveyed.

Manganate solutions, free from permanganate, can be prepared in N—10N-alkali, and a method involving direct titration with arsenite has been developed for the analysis of MnO_4^{2-} in the presence of organic compounds.

Hypomanganate (MnO_4^{3-}) solutions are stable enough in cold 8—10N-alkali for their oxidising properties to be studied. They can be prepared free from MnO_4^{2-}.

Alkaline manganate oxidations of organic compounds, though slow, resemble those of alkaline permanganate in not being specific reactions, but the reactions of the feeble oxidiser MnO_4^{3-} are sharply specific. Ketones, phenols, and some alcohols are oxidised by MnO_4^{2-} in two stages, MnO_4^{3-} being a recognisable intermediate. It is considered that these oxidations involve 1-electron transfer. Olefinic acids are oxidised by MnO_4^{3-} but not by MnO_4^{2-}, and for cinnamic and fumaric acids it has been shown that the oxidation proceeds *via* a *cis*-glycol.

In Part I of this series [1] a survey was made of oxidations of organic compounds by alkaline permanganate in the presence of barium salts, so that the reactions ceased when all the MnO_4^- anions had been converted into insoluble barium manganate. The present paper describes a similar survey of oxidations of organic compounds by alkaline solutions of potassium manganate and also by strongly alkaline solutions of the blue salt K_3MnO_4 described by Lux [2] and shown by Klemm [3] to contain quinquevalent manganese. We suggest that this salt should be called potassium hypomanganate.

Manganate solutions were prepared by heating potassium permanganate in concentrated potassium hydroxide solution and then extracting the product with carbonate-free solutions of alkali so that dissolution never occurred into a liquid of alkalinity less than 1·0N. In this way the disproportionation of manganate to permanganate and manganese dioxide was prevented and by filtration through asbestos clear green solutions could be obtained which were shown spectroscopically to be permanganate-free (Fig. 1). It was found that these solutions did not oxidise potassium cyanide at an appreciable rate, and consequently the rapid oxidation of cyanide by alkaline permanganate:

$$2MnO_4^- + CN^- + H_2O = 2MnO_4^{2-} + CNO^- + 2H^+$$

which was used in Part I for the estimation of alkaline permanganate could be employed as an additional check on the reactivities of alkaline manganate solutions to ensure that the oxidations which they effected were not initiated by traces of permanganate. The oxidising power of filtered manganate solutions was shown to be within 1% of that required for sexavalent manganese by estimating total manganese colorimetrically, and the total oxidising power was obtained by adding oxalic acid in excess, then acidifying and back-titrating the solution with acid permanganate; but a different reaction had to be used for the direct estimation of soluble manganate in the presence of both free alkali and organic substances, such as oxalate. After alternative procedures had been explored it was found that direct titration with sodium arsenite solution could be used at all alkalinities provided that the end-point, shown by the complete disappearance of the green MnO_4^{2-} anion, was

* Part VI, *J.*, 1955, 497.

[1] Drummond and Waters, *J.*, 1953, 435.
[2] Lux, *Z. Naturforsch.*, 1946, **1**, 281.
[3] Klemm, Proc. Internat. Symp. Reactivity of Solids, Gothenburg, 1952, **1**, 173 (*Chem. Abs.*, 1954, **48**, 12,602).

made visible by centrifuging the reacting solutions after each successive addition of arsenite to coagulate and sediment the brown hydrated manganese dioxide. In the presence of added substances colorimetric analysis of alkaline manganate solutions proved impracticable, for it was impossible to prevent entirely their very slow decomposition to hydrated manganese dioxide which, when colloidal, gave the solutions a yellowish tinge and considerably affected their absorptivities. The concentration of free alkali in dilute manganate solutions could be determined by adding hydrogen peroxide in slight excess and then, after warming and filtering, titrating the mixture with acid in the usual manner.

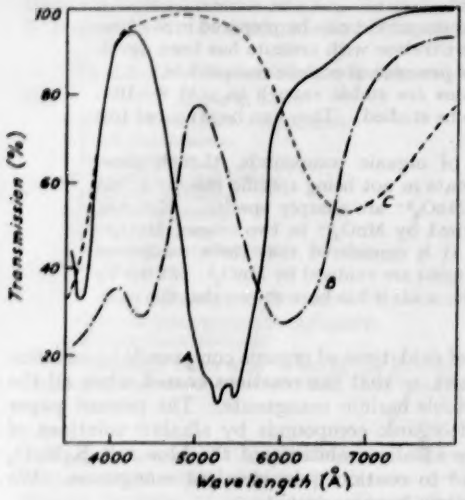


FIG. 1. *Absorption spectra of (A) permanganate anion, MnO_4^-, (B) manganate anion, MnO_4^{2-}, and (C) hypomanganate anion, MnO_4^{3-}.*

The spectra were measured in a cell of 1 cm. thickness with solutions that contained 0·024 g. of manganese per l.

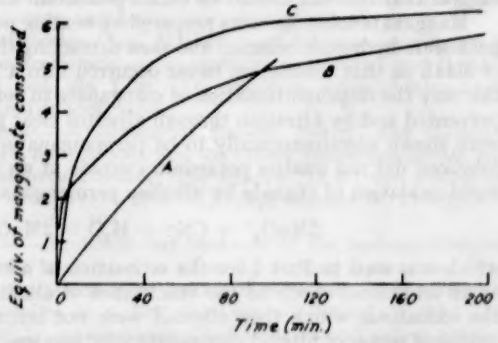


FIG. 2. *Oxidations of Unsaturated Acids with Alkaline Manganate.*

A, Maleic acid, $2·0 \times 10^{-3}$M. Manganate, $2·43 \times 10^{-3}$M. Alkali 0·75N.

B, Cinnamic acid, $2·65 \times 10^{-3}$M. Manganate, $3·14 \times 10^{-3}$M. Alkali, 0·60N.

C, α-Phenylcinnamic acid, $2·94 \times 10^{-3}$M. Manganate, $3·14 \times 10^{-3}$M. Alkali, 0·65N.

Potassium hypomanganate, K_3MnO_4, was made by the fusion together of manganese dioxide, potassium hydroxide, and sodium nitrite as described by Lux.[2] Fusion of potassium permanganate with sodium hydroxide at a high temperature [4] also gave a product which on dissolution in strong alkali yielded a similar blue solution free from nitrite. Extraction of these fusion mixtures with 10N-potassium hydroxide gave pale blue solutions of 10^{-2}—10^{-3} molarity for which the ratio (total manganese) : (oxidising power) corresponded within 5% with that required for quinquevalent manganese. These solutions had an absorption spectrum (Fig. 1, curve *C*) different from that of alkaline manganate and had much lower oxidising power. Provided that, by careful exclusion of atmospheric carbon dioxide, the concentration of free alkali was not reduced below 8N, the solutions could be kept at 0° for 3 days without deposition of manganese dioxide. When the alkalinity was

[4] Cf. Scholder and Waterstradt, *Z. anorg. Chem.*, 1954, **277**, 172.

reduced to 4N, irreversible disproportionation to manganate and hydrated manganese dioxide was evident within 10 minutes and at N-alkalinity there was no evidence of the existence of the MnO_4^{3-} anion.[5]

When hypomanganate solutions are partially reduced the separation of colloidal hydrated manganese dioxide tends, at first, to give them a greenish tinge which is easily confused with that of dilute manganate solutions, but clear sky-blue solutions can be obtained by centrifuging and then filtering them. Even in the strongest alkali no indication can be found of the existence of any dissolved form of quadrivalent manganese, *e.g.*, MnO_4^{4-}.

The oxidising powers of septa-, sexa-, and quinque-valent manganese decrease markedly in the order $MnO_4^- > MnO_4^{2-} > MnO_4^{3-}$, as would be expected for reactions that result in increase in the electronic charge on the ion. Alkaline permanganate appears to convert hypomanganate instantaneously into manganate:

$$MnO_4^- + MnO_4^{3-} \longrightarrow 2MnO_4^{2-},$$

so that, apart from the fact that strongly alkaline permanganate easily decomposes to give manganate and oxygen,[6] any direct check as to whether the permanganate could be degraded in alkali in a one-stage process by the 2-electron reduction, $MnO_4^- + 2e \longrightarrow MnO_4^{3-}$, would seem to be impracticable experimentally, particularly since the radiochemical change between manganate and permanganate anions in alkaline solution is immediate.[7] However the rapidity of these electron transfers between ions of similar atomic structure shows that there is no experimental reason for rejecting the postulate that some of the reactions of alkaline (or perhaps even acid) permanganate proceed by 2-electron transitions [8] even when, as under the conditions chosen in Part I,[1] the final net reduction of permanganate does not go below the oxidation level of sexavalent manganese.

Much more definite experimental information can be obtained with regard to the mechanisms of oxidations effected by the manganate anion, but since hypomanganate rapidly decomposes at alkalinities below 4N it is only with reactions that can be carried out in very strongly alkaline solutions that discrimination can be made between the 1-electron and the 2-electron oxidation process. For instance, oxidation of aldehydes cannot be examined. Filtered manganate solutions, if prepared from "AnalaR" reagents free from traces of metals such as iron, appear to be reasonably stable in very strong alkali and their reactions with organic substances (see below) give no indication of the occurrence of an equilibrium with hydroxyl anion, $MnO_4^{2-} + OH^- \rightleftharpoons MnO_4^{3-} + \cdot OH$, similar to that which has been postulated for the decomposition of permanganate in concentrated alkali.[6,9]

Amongst inorganic reactants both sulphite and thiosulphate anions can be used to form hypomanganate.[2] The occurrence of the reactions

$$MnO_4^{2-} + SO_3^{2-} \longrightarrow MnO_4^{3-} + \cdot SO_3^-$$

$$MnO_4^{2-} + S_2O_3^{2-} \longrightarrow MnO_4^{3-} + \cdot S_2O_3^-$$

accords with expectations since the dimers of the radical-anions $\cdot SO_3^-$ and $\cdot S_2O_3^-$, the dithionates and tetrathionates, are well known. In contrast to this, arsenite does not convert manganate into hypomanganate; the oxidation of arsenite therefore seems to be a 2-electron process: again, the anion $As_2O_6^{4-}$ is unknown.

The oxidation of hydrogen peroxide by strongly alkaline permanganate also occurs in 1-electron stages:

$$MnO_4^- + O_2H^- \longrightarrow MnO_4^{2-} + HO_2\cdot$$

$$MnO_4^- + HO_2\cdot \longrightarrow MnO_4^{2-} + H^+ + O_2$$

$$MnO_4^{2-} + O_2H^- \longrightarrow MnO_4^{3-} + HO_2\cdot, \text{ etc.}$$

[5] Cf. Scholder, Fischer, and Waterstradt, *ibid.*, p. 234.
[6] Symons, *J.*, 1953, 3956; 1954, 3676.
[7] Libby, *J. Amer. Chem. Soc.*, 1940, **62**, 1936; Adamson, *J. Phys. Coll. Chem.*, 1951, **55**, 293; Amphlett, *Quart. Rev.*, 1954, **8**, 237.
[8] Cf. Wiberg and Stewart, *J. Amer. Chem. Soc.*, 1955, **77**, 1786.
[9] Duke, *ibid.*, 1948, **70**, 3975.

TABLE 1. *Oxidations of organic compounds with potassium manganate (organic substrate in large excess).*

Compound	Reaction in N-KOH *	Reaction in 10N-KOH †
Saturated acids.		
Oxalic, acetic, adipic	O	O
Benzoic	O	—
Malonic, ethylmalonic	O	+
Diethylmalonic	O	O
*iso*Butyric, *iso*valeric	—	+
Formic	C, F	B
Unsaturated acids.		
Maleic	C, S	—
Fumaric	C, S	C
Crotonic	C, SS	C
Hex-2-enoic	C, SS	—
Undecenoic	C, S	—
Cinnamic	C, S	C
Carbonyl compounds.		
Acetone	C, SS	B
Ethyl methyl ketone	C, F	—
*cyclo*Hexanone	C, S	B
Benzaldehyde	C, F	—
Pyruvic acid, lævulic acid, 3-oxopimelic acid	C, F	B
Ethers.		
Diethyl ether, dioxan	O	O
Anisole	O	—
Primary alcohols.		
Methanol	C, VS	C
Ethanol	C, SS	C
Glycollic acid	C, S	B
γ-Hydroxybutyric acid	C, SS	C
Benzyl alcohol	—	C
Secondary alcohols.		
Propan-2-ol	C, VS	C
Lactic acid	C, SS	B
Malic acid	C, SS	—
Tertiary alcohols.		
tert.-Butanol	O	O
Citric acid, benzilic acid	O	—
Diols.		
Butane-1 : 2- and -2 : 3-diol	C, FF	C
Butane-1 : 3-diol	C, S	—
Pinacol	—	+
Hydrobenzoin	C, FF	—
Tartaric acid	C, S	—
Sorbitol	C, FF	—
Phenols.		
Phenol, *p*-cresol	C, F	A
p-Benzylphenol	—	A
Mesitol	C, FF	A
4-Benzyl-2 : 6-dimethylphenol	C, F	—
2 : 6-Dimethoxyphenol	—	A
Salicylic acid	C, S	A
Catechol	—	B

* O = No reaction; C = complete reduction of the manganate; FF = reduction of manganate complete in <2 hr.; F = reduction of manganate complete in 2—5 hr.; S = reduction of manganate complete in 6—12 hr.; SS = reduction of manganate complete in 12—24 hr.; VS = reduction of manganate requires over 24 hr.

† O = No reaction in 3 days; + = slight reaction in 3 days; A = reduction of manganate to hypomanganate; no further reaction; B = reduction of manganate to manganese dioxide, but visibly passing through the hypomanganate stage; C = reduction of manganate to manganese dioxide without any noticeable hypomanganate intermediate.

since by adding very dilute hydrogen peroxide dropwise to potassium permanganate in cold concentrated alkali the successive colour changes, purple ⟶ green ⟶ light blue ⟶ deep green ⟶ brown turbidity (MnO_2), can be observed, and at the appropriate stages the characteristic absorption spectra of the MnO_4^{2-} and MnO_4^{3-} ions can be measured. The penultimate deep green colour is that of a mixture of blue hypomanganate and brown suspended manganese dioxide, for by filtration through asbestos the latter can be removed and there remains a clear sky-blue filtrate.

Oxidation of Organic Compounds.—The results of our survey of the oxidation of alkali-soluble organic compounds by potassium manganate and potassium hypomanganate solutions are summarised in Tables 1 and 2.

TABLE 2. *Oxidations of organic compounds by potassium hypomanganate in* 10N-*potassium hydroxide solution at* 0°.

Unsaturated acids.	
Cinnamic, crotonic, hex-2-enoic, maleic, fumaric	Not attacked
Carbonyl compounds.	
Acetone, lævulic acid, 3-oxopimelic acid	Slow reduction of MnO_4^{3-}
Alcohols.	
Methanol, ethanol, propan-2-ol	Slow reaction
tert.-Butanol	Not attacked
Phenols.	
Phenol, *p*-cresol, salicylic acid, *p*-hydroxybenzoic acid, catechol	Not attacked

Table 1 shows that alkaline manganate is no more specific an oxidising agent than is potassium permanganate (cf. Part I), though it is very much slower in its action. Amongst aliphatic compounds only saturated straight-chain acids, ethers, and tertiary monohydric alcohols resist oxidation; these are also the only ones not oxidised by weakly alkaline permanganate. Strongly alkaline hypomanganate is a very mild oxidising agent and, as Table 2 shows, it is much more specific in its action, for whilst it does slowly oxidise primary and secondary alcohols and ketones it does not oxidise olefins. This selectivity in the reactions of MnO_4^{3-} strikingly resembles that observed with the manganic cation [1] and since other mild 1-electron abstracting reagents, *e.g.*, alkaline ferricyanide [10] and alkaline silver and cupric salt solutions, show a similar selectivity it can be inferred that compounds such as olefins which are easily oxidised by manganate but not by hypomanganate react by single-stage 2-electron transfer. The tests made with strongly alkaline manganate solutions (Table 1, last column) substantiate this view, for it was found that certain manganate oxidations of alcohols and ketones visibly proceed in stages, the conversion of green MnO_4^{2-} into blue MnO_4^{3-} being much faster than the subsequent reduction of hypomanganate to insoluble hydrated manganese dioxide. With monohydric phenols only the 1-electron change from manganate to hypomanganate occurs. Parts II and VI of this series,[1, 11] and also investigations of the oxidations of aldehydes and ketones with alkaline ferricyanide,[10] ceric salts,[12] the free radical $\cdot ON(SO_3K)_2$,[13] and even lead tetra-acetate [14] consistently show that the oxidations of aldehydes and ketones in aqueous solution most easily occur by 1-electron abstraction from their enolic forms and, as in the present work, indicate the similarity in behaviour between enol anions and phenol anions. Oxidation of aldehydes and ketones by attack at an α-CH group, and oxidation of phenols to dimeric products, may therefore be regarded as diagnostic 1-electron-removal processes: even more diagnostic of an oxidation of this type, however, is lack of reactivity at an isolated C=C bond.

In regard to oxidations of saturated acids our observations are consistent with those of Kenyon and Symons [15] who have shown that tertiary CH groups are slowly attacked by

[10] Speakman and Waters, *J.*, 1955, 40.
[11] Drummond and Waters, *J.*, 1955, 497.
[12] Shorter and Hinshelwood, *J.*, 1950, 3276; Shorter, *idem*, p. 3425.
[13] Allen and Waters, *J.*, 1956, in the press.
[14] Ichikawa and Yamaguchi, *J. Chem. Soc. Japan*, 1952, **73**, 415.
[15] Kenyon and Symons, *J.*, 1953, 2129, 3580.

both permanganate and manganate. The resistance of ethers to oxidation by manganate in strong alkali can be compared with their stability towards permanganate in weak alkali (Part I). This probably indicates that the postulated equilibria [6]:

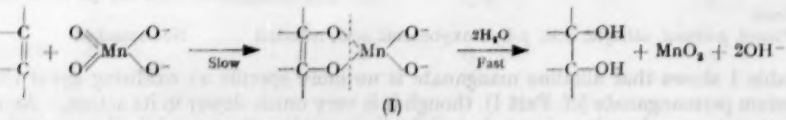
$$MnO_4^- + OH^- \rightleftharpoons MnO_4^{2-} + \cdot OH$$

$$MnO_4^{2-} + OH^- \rightleftharpoons MnO_4^{3-} + \cdot OH$$

give negligible concentrations of hydroxyl radicals at the hydroxyl-anion concentrations that have been used. However, since no reactions of hydroxyl radicals in strongly alkaline solution have yet been studied, it is also possible that the dissociation, $\cdot OH + OH^- \rightleftharpoons \cdot O^- + H_2O$, gives, in the radical anion $\cdot O^-$, a weaker oxidising agent than free hydroxyl (compare the reactivities of MnO_4^- and MnO_4^{2-}).

The observations that the anions of olefinic acids are oxidised by alkaline manganate without giving hypomanganate, and that olefins are not attacked by hypomanganate, are of particular interest since they indicate that the oxidation of the C=C group can easily occur by a 2-electron-transfer process.

The cyclic oxidation process, resembling that involved in oxidation by osmium tetroxide,[16] that was considered with disfavour in Part I for the oxidation of olefins by alkaline permanganate, is equally attractive for the interpretation of their oxidation by alkaline manganate:



(I)

We are now of the opinion that this does represent the probable course of both these oxidations, for our present experimental check of the extreme rapidity of the reaction, $MnO_4^{3-} + MnO_4^- \longrightarrow 2MnO_4^{2-}$, invalidates the argument that one should expect to find free MnO_4^{3-}, or at least some hydrated manganese dioxide, as invariable products in the alkaline permanganate oxidations of olefins. If transient cyclic manganese compounds such as (I) are formed in these oxidations, it would be expected that a colour change indicative of complex formation might be observable when olefins and manganate solutions are mixed, but in no experiment have we been able to show any change other than the yellowing colour due to the separation of colloidal hydrated manganese dioxide. Oxidation of olefins by very dilute permanganate in very strong alkali gives almost immediately the clear green colour of the manganate anion.

If the permanganate and the manganate oxidation of olefins have similar mechanisms they should give stereochemically identical (*cis*-)products. For oxidation of both cinnamic and fumaric acid we have shown that this is indeed the case by isolating from the manganate oxidation of the former some of the high-melting (140°) β-phenylglyceric acid that is also obtainable by permanganate oxidation, and from the latter some racemic acid. These dihydroxy-acids could be obtained only in low yields, for the manganate anion easily brings about their further oxidation producing, from cinnamic acid a mixture of benzoic and oxalic acid, and from fumaric and maleic acid only oxalic acid. Only with cinnamic acid did the rate of removal of manganate change noticeably at the equivalent point for glycol formation. Manganate oxidation of olefins therefore does not afford a practicable route for the preparation of *cis*-glycols. Indeed the manganate oxidation of 1 : 2-glycols occurs much more rapidly than the manganate oxidation of monohydric alcohols, and does not appear to pass through the hypomanganate stage.

Experimental

Preparation of Alkaline Manganate Solutions.—" AnalaR " potassium hydroxide (50 g.) and potassium permanganate (8 g.) were intimately mixed with water (2 ml.) in a nickel crucible, heated gradually to 350°, and kept thereat until the melt was quiescent (3 hr.). After cooling

[16] Criegee, *Annalen*, 1936, **522**, 75.

in a desiccator the product was pulverised and dissolved slowly, with shaking, in 0·5N-potassium hydroxide (in boiled-out distilled water). The manganate solution was stored for 24 hr., then filtered through sintered glass and then through an asbestos pad. Its absorption spectrum (Fig. 1, curve *B*), measured with a Unicam spectrometer (Model SP 600), was not altered when potassium cyanide solution was added to remove possible contaminating permanganate. In solutions of dilution suitable for spectrographic examination of purity, total manganese was estimated colorimetrically with light of λ 3600 Å after complete oxidation to permanganate with potassium periodate in phosphoric acid solution. Total reducing power, calc. as $Mn \equiv 2H_2C_2O_4$ for the reaction

$$MnO_4^{3-} + 2H_2C_2O_4 + 4H^+ = Mn^{3+} + 4CO_2 + 4H_2O$$

was determined by acidification in the presence of an excess of oxalic acid and back-titrating at 60° with standard permanganate. Results (g. of Mn per l.) found for four solutions colorimetrically and by means of oxalate respectively were : 0·0238, 0·0239; 0·0316, 0·0319; 0·0314, 0·0313; 0·0302, 0·0301.

Estimation of Manganate in the Presence of Organic Substances.—The reaction between manganate and arsenite solutions does not appear to have been studied. Tests showed that freshly precipitated manganese dioxide appreciably oxidises neutral sodium arsenite solution in 24 hr. and that addition of excess of arsenite to alkaline manganate solutions and back-titration with standard iodine was unreliable. Direct titration of alkaline manganate with *ca.* 0·02N-sodium arsenite, however, proved practicable. The arsenite solution was added slowly, with shaking, from a microburette until the green colour of the solution had almost disappeared (*ca.* 95% reaction). The titration mixture was then centrifuged for 2 min. to coagulate manganese dioxide, and the titration was continued dropwise, with periodic centrifuging, until a colourless solution resulted, 5 min. of centrifuging being allowed as soon as the faint yellow opalescence of suspended colloidal manganese dioxide seemed to replace the green tinge of the supernatant liquid. Results, calculated from the equation

$$MnO_4^{3-} + AsO_3^{3-} + H_2O = MnO_2 + AsO_4^{-3} + 2OH^-$$

for three solutions, obtained respectively by arsenite and colorimetrically for total Mn (g./l.) were : 1·095, 1·105; 0·972, 0·977; 0·936, 0·940.

This direct titration of manganate with standard arsenite solution proved satisfactory for solutions of varying alkalinity. Addition of oxalate did not affect the end-point and the progress of many slow oxidations of organic compounds could be followed satisfactorily (see Fig. 2).

Estimation of the Alkalinity of Manganate Solutions.—Dilute solutions of potassium manganate could be decomposed to manganese dioxide by adding hydrogen peroxide, excess of which decomposes catalytically. Free alkali was then determined by acidification with standard acid and back-titration to neutrality (phenolphthalein). However this simple method was not reliable for concentrated manganate solutions.

Stability of Potassium Manganate Solutions.—Solutions of potassium manganate in N-alkali, containing about 0·024 g. of manganese per l., were stored in the dark at room temperature, filtered periodically, and examined colorimetrically. The decay was about 1% in 5 days. Boiling causes more rapid decomposition and consequently reactions at elevated temperatures could not be examined. Solutions of less than N-alkalinity are much less stable.[17] Addition of a manganous salt to manganate in N-alkali brings about the immediate separation of a blackish-brown precipitate of manganese dioxide, but filtration leaves only MnO_4^{3-} in the solution which exhibits no sign of the absorption peak at 6700 Å characteristic of MnO_4^{3-}.

Preparation of Hypomanganate Solutions.—(*a*) [2] An intimate mixture of manganese dioxide (8 g.) and sodium peroxide (2 g.) was added slowly with stirring to a fused mixture of sodium nitrite (30 g.) and sodium hydroxide (15 g.) kept a bright red heat. After being heated for a further 20 min. the mixture was allowed to cool in a desiccator. Portions of the dry stored product were pulverised and shaken with 10N-potassium hydroxide in which the hypomanganate is not very soluble. The material which dissolved in the first portion of the alkali was discarded, fresh potassium hydroxide solution was then introduced, and this second solution was kept at 0° for 12 hr. in a stoppered flask and then filtered through asbestos. The clear filtrate was sky-blue and had the absorption spectrum given in Fig. 1, curve *C*.

(*b*) [4] A hypomanganate solution giving an identical absorption spectrum and free from

[17] Schlesinger and Siems, *J. Amer. Chem. Soc.*, 1924, **46**, 1965.

nitrite or nitrate was obtained by fusing together at red heat potassium permanganate and sodium hydroxide, extracting the bright blue product with 10N-potassium hydroxide, storing the extract for some hours at 0°, and then filtering. Qualitative examination showed that the sodium hydroxide which had been used contained a trace of iron, which possibly catalysed the reduction of manganate to hypomanganate. The contamination by nitrite of solutions obtained by method (*a*) did not affect their oxidising powers under strongly alkaline conditions. The stability of the solutions was in accord with the findings of Scholder *et al.*[5]

Estimation of Hypomanganate Solutions.—Hypomanganate solutions prepared by method (*a*) could not be estimated by Lux's procedure[2] for the analysis of his solid, $Na_2MnO_4.10H_2O$, since they contained nitrite, which reacts with permanganate the moment any solution is acidified. Even neutralisation with aqueous sodium hydrogen carbonate is attended by some local formation of permanganate. When very dilute hypomanganate in concentrated alkali was added to permanganate in dilute alkali the disproportionation $MnO_4^- + MnO_4^{3-} = 2MnO_4^{2-}$ occurred instantly without separation of manganese dioxide, and consequently it was possible to reduce the alkalinity of nitrite-free (*b* above) hypomanganate solutions to pH 3—4 with sodium hydrogen carbonate, keep the product for 6 hr. so that the reaction

$$2MnO_4^{3-} + 2H_2O = MnO_4^{2-} + MnO_2 + 4OH^-$$

proceeded to completion, and then titrate the resulting very dilute manganate with standard arsenite (using a micro-burette). Unless the alkalinity is reduced in this way the reaction between arsenite and hypomanganate occurs very slowly indeed. The oxidising powers, calculated for the net reduction $Mn^V \longrightarrow Mn^{IV}$, agreed within 5% with the total manganese content determined colorimetrically after oxidation to permanganate.

Oxidations of Organic Substances (*See Tables* 1 *and* 2).—For the observations in N-alkali 25 ml. of 0·002N-manganate were added to 25 ml. of 0·01M-solutions or emulsions of the organic substrates which had been made of normal alkalinity by the addition of 2N-potassium hydroxide.

For the observations in 10N-alkali, 25 ml. of 0·005N-manganate solution in 10N-potassium hydroxide were added to 25 ml. of 10N-potassium hydroxide in which 0·5 g. of the organic substance had been dissolved. These mixtures were examined over a period of 3 days.

For the observations with hypomanganate 10 ml. of approx. 0·01N-hypomanganate (method *a*), in 10N-potassium hydroxide, were added to solutions made by shaking 0·5 g. of the organic compound with 20 ml. of 10N-potassium hydroxide. These mixtures were kept at 0° and examined during 24 hr. Thus in the reactions carried out in 10N-alkali the organic substrates have been used in very large excess.

Quantitative Oxidations with Manganate in N-*Potassium Hydroxide.*—The substances listed in Table 3, in N-potassium hydroxide, were kept for 5 days in a 3-fold excess of alkaline manganate at room temperature. Titrations of aliquot portions showed that reactions were virtually complete after 4 days. The results indicate that alkaline manganate and alkaline permanganate (Part I) degrade organic compounds to a similar degree.

TABLE 3

Acid	Molarity × 10^3	No. of tests	Equivs. of manganate consumed per mole
Glycollic	2·52	4	4·02 ± 0·04
Cinnamic	0·83	3	7·18 ± 0·12
Maleic	1·03	4	7·45 ± 0·18
Fumaric	1·11	3	7·22 ± 0·18
Crotonic	1·21	4	9·43 ± 0·08
Hex-2-enoic	1·13	4	12·47 ± 0·18

Exploratory kinetic measurements at 25° are shown in Fig. 2. Only with cinnamic and α-phenylcinnamic acid is there any sign of a discontinuity of the oxidation rate at the stage of 1 : 2-glycol formation.

Products from the Manganate Oxidation of Unsaturated Acids.—(*a*) *Cinnamic acid.* A neutralised 10% solution of cinnamic acid (5 g.) was added rapidly with vigorous shaking to a solution at 0° of potassium manganate (250 ml., 0·13N-MnO_4^{2-}) which had been reduced to 0·2N-alkalinity by the addition of sodium hydrogen carbonate solution. After 3 min. the cold alkaline solution was extracted with ether to remove benzaldehyde which had formed in quantity, acidified, treated with sulphur dioxide to remove manganese dioxide, and extracted continuously with ether for 12 hr. The extract was washed with 10 ml. of dry ether, and the remaining solid (1 g.) was extracted with 100 ml. of boiling benzene. The solution, after dilution with a

further 50 ml. of benzene, gave crystals, m. p. 138—139°, on cooling. Further crystallisation of these from benzene gave β-phenylglyceric acid, m. p. 140·5° (Found: C, 59·3; H, 5·5. Calc. for $C_9H_{10}O_4$: C, 59·4; H, 5·6%).

(*b*) *Fumaric acid.* To fumaric acid (10 g.) in potassium hydroxide solution (100 ml.) of resultant alkalinity 0·1N was added dropwise at 0°, with stirring, 0·11N-manganate (350 ml.) also of alkalinity 0·1N. After 40 minutes' reaction below 5° the mixture was filtered through sintered glass, and the filtrate was neutralised with acetic acid. From this lead salts were precipitated by the addition of a concentrated solution of lead acetate (40 g.). These salts were suspended in ethanol (150 ml.) and decomposed with hydrogen sulphide. Evaporation of the alcoholic solution yielded a mixture of solid acids (1 g.) of which about half dissolved easily in a little cold water (5 ml.). From this solution by repeated crystallisation from small volumes of alcohol and water there was eventually obtained 0·2 g. of the monohydrate of racemic acid, m. p. and mixed m. p. 202°. *meso*Tartaric acid, m. p. 140°, is much too soluble in water for crystallisation on this small scale.

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THE DYSON PERRINS LABORATORY, OXFORD. [*Received, September 19th*, 1955.]

145. *The Thermal Decomposition of Lead Dioxide in Air.*

By GEORGE BUTLER and J. L. COPP.

It has been shown that in the decomposition of lead dioxide two oxides, α-PbO_x and β-PbO_x, are formed. The composition of α-PbO_x is close to Pb_7O_{11} and that of β-PbO_x close to Pb_3O_8. The crystal structures of these two oxides are very similar and it is suggested that this is possibly why many earlier workers found only one intermediate oxide.

AN extensive literature on the decomposition of lead dioxide and the oxidation of lead monoxide provides definite evidence for the existence of further oxides with structures of the same intermediate type as that of red lead, but fails to define unambiguously their number and composition. Early work [1] indicates that an intermediate oxide, Pb_3O_4, is formed on decomposition of lead dioxide. Moles and Vitoria,[2] Renker,[3] and Baroni [4] assert that this is the only intermediate oxide formed in the composition range PbO_2—$PbO_{1·33}$. Renker considers that the structure of this oxide persists over a range of composition $PbO_{1·50}$—$PbO_{1·34}$, whereas Baroni assigns to a similar oxide a range extending from $PbO_{1·50}$ to $PbO_{1·66}$.

Eberius and Le Blanc [5] conclude that a black modification of red lead, with a composition range $PbO_{1·14}$—$PbO_{1·66}$, is formed on oxidation of lead monoxide, and that an oxide with the same structure, with a composition range $PbO_{1·65}$—$PbO_{1·33}$, is formed by decomposition of lead dioxide. Fischer and Ploetze [6] and Clark and Rowan [7] refer to an intermediate oxide Pb_5O_8. The latter workers also identified a further intermediate structure, PbO_x, in the products of oxidation of lead monoxide. Holtermann and Laffitte [8] have identified an intermediate oxide, formed at high pressures from lead dioxide, as Pb_7O_{11}.

The significance of these conflicting reports has been reduced considerably by the recent work of Byström [9] and of Katz.[10] Byström considers that two intermediate oxides,

[1] (*a*) Debray, *Compt. rend.*, 1878, **86**, 813; (*b*) Carnelley and Walker, *J.*, 1888, **53**, 59; (*c*) Milbauer, *Chem. Ztg.*, 1909—1914.
[2] Moles and Vitoria, *Anales Fis. Quim.*, 1929, **27**, 52.
[3] Renker, *Bull. Soc. chim. France*, 1936, **3**, 981.
[4] Baroni, *Gazzetta*, 1938, **68**, 387.
[5] Eberius and Le Blanc, *Z. phys. Chem.*, 1932, **160**, *A*, 129.
[6] Fischer and Ploetze, *Z. anorg. Chem.*, 1912, **75**, 10.
[7] Clark and Rowan, *J. Amer. Chem. Soc.*, 1941, **63**, 1305.
[8] (*a*) Holtermann and Laffitte, *Compt. rend.*, 1937, **204**, 1813; (*b*) Holtermann, *Bull. Soc. chim. France*, 1938, **5**, 961; (*c*) *idem*, *Ann. Chim.*, 1940, **14**, 121.
[9] Byström, *Arkiv Kemi, Mineralog. Geol.*, 1945, **20**, *A*, No. 11.
[10] Katz, Thesis, Paris, 1949.

α-PbO_x ($1{\cdot}67 \geqslant x \geqslant 1{\cdot}50$) and β-$PbO_x$ ($1{\cdot}51 \geqslant x \geqslant 1{\cdot}47$) exist in the composition range PbO_2—$PbO_{1{\cdot}33}$. Katz reports that a continuous series of solid solutions is formed between the oxides Pb_7O_{11} and Pb_3O_4, and that the solution of composition Pb_2O_3 exhibits the greatest order.

We have attempted to define the number of intermediate lead oxide structures formed on decomposition of lead dioxide, their ranges of composition, and crystal structures. To this end, *X*-ray and chemical analysis have been applied systematically to the products formed on progressive decomposition of lead dioxide in air, (1) at a series of constant temperatures, and (2) at steadily increasing temperatures, *i.e.*, under the conditions of differential thermal analysis.

Experimental

Materials.—Two preparations of lead dioxide were used in these decomposition experiments. The first was a coarse granular material of extreme hardness, prepared electrolytically from lead nitrate by Hamer's method.[11] The product was washed with water, dried at 120°, and stored over phosphoric oxide until required. It contained 84·0% of quadrivalent lead (determined iodometrically) (Calc. for PbO_2: 86·62%) and was the subject of only a few experiments.

The second preparation used in all later work was a commercial product of A.R. quality; as its content of quadrivalent lead (84·4%) was not changed by successive treatments with nitric acid, it was free from traces of lower lead oxides, and was very pure. This conclusion was confirmed by determining its content of total lead (Found, by means of lead molybdate: Pb, 86·13 ± 0·25%) and by heating a sample of the oxide to constant weight at 600° (Found: PbO, 93·20 ± 0·02. Calc.: 93·31%).

Chemical Analysis.—It has been assumed in all previous work that a determination of the percentage of quadrivalent lead (*P*) in a lead oxide system is sufficient to establish its overall formula PbO_x, where $x = 207{\cdot}21(P + 100)/(207{\cdot}21 \times 100 - 16P)$. We have accepted this convention, and determined *P* by a modification of Bunsen's method described by Eberius and Le Blanc;[12] a known weight of a lead oxide is dissolved and reduced in an excess of hot concentrated hydrochloric acid. The chlorine produced is carried by a stream of carbon dioxide to absorption bulbs filled with potassium iodide solution, the iodine liberated being titrated with standard sodium thiosulphate.

Carefully calibrated volumetric apparatus and weights were used throughout and only reagents of A.R. quality were employed. At first, low and erratic results were obtained by this method, but this was traced to a volatile impurity in the A.R. hydrochloric acid, and was easily eliminated by using constant-boiling acid. The absolute errors inherent in the method were shown to be less than 0·5% by analysing a standard solution of potassium permanganate instead of the lead oxide. Thus we cannot agree with Mrgudich and Clark's statement[13] that the method gives results that are 5% too low.

The O : Pb ratio *x* can be calculated graphically directly from the titre, expressed as ml. of N-thiosulphate per g. of oxide (*V*), from the formula $x - 1 = 223{\cdot}21V/(2000 - 16V)$. A typical set of data from a decomposition experiment is given in Table 1.

Table 1. *Analyses of the decomposition products of A.R. lead dioxide at* 343° ± 2°.

Heating time (hr.)	Wt. of oxide taken (g.)	Ml. of N-$Na_2S_2O_3$ per g.	*x*	Heating time (hr.)	Wt. of oxide taken (g.)	Ml. of N-$Na_2S_2O_3$ per g.	*x*	Heating time (hr.)	Wt. of oxide taken (g.)	Ml. of N-$Na_2S_2O_3$ per g.	*x*
0	—	8·152	1·973	22·4	0·1122	6·252	1·734	200·2	0·1490	4·901	1·569
2·1	0·1334	7·812	1·930		0·1328	6·277	1·737	455·2	0·1226	4·914	1·570
	0·1770	7·815	1·930	31·5	0·1254	5·720	1·669		0·1377	4·912	1·570
4·7	0·1370	7·557	1·897		0·1049	5·745	1·672	787·0	0·1611	4·888	1·567
	0·2211	7·557	1·897	50·0	0·0924	5·060	1·586		0·1645	4·884	1·566
8·9	0·0997	7·175	1·850	102·1	0·1303	8·897	1·568	2232	0·2935	4·868	1·565
	0·1263	7·196	1·852		0·2350	4·915	1·570		0·2475	4·867	1·565

X-Ray Analysis.—Specimens for *X*-ray analysis were prepared by coating the surface of a glass fibre with a paste of a lead oxide in "Durofix" glue to give a specimen less than 0·5 mm. in diameter. These were exposed for 30 min. in a 9-cm. camera of the back-reflection type to

[11] Hamer, *J. Amer. Chem. Soc.*, 1935, **57**, 339.
[12] Eberius and Le Blanc, *Z. anal. Chem.*, 1932, **89**, 81.
[13] Mrgudich and Clark, *Ind. Eng. Chem. Anal.*, 1937, **9**, 256.

filtered Co-$K\alpha$ radiation generated at 50 kv and 20 ma. The wavelengths of the incident radiation, which enters the camera through the centre of the film, were taken[14] as $\alpha_1 = 1{\cdot}78890$ Å, $\alpha_2 = 1{\cdot}79279$ Å, $\alpha = 1{\cdot}7902$ Å. The positions of the diffraction lines on the exposed film were measured with a simple scanning instrument designed by Gibson,[15] and the lattice parameters derived therefrom were extrapolated to a Bragg angle of 90° by Nelson and Riley's method.[16]

For lead dioxide a good resolution of the $K\alpha_1$–$K\alpha_2$ doublets was achieved at high Bragg angles, and here the precision of the parameter determinations is probably better than $\pm 0{\cdot}001$ Å. Oxides with an oxygen content lower than about $PbO_{1.8}$ gave more diffuse diffraction lines in the high-angle region and in consequence the precision of parameter determinations is reduced to about 0·005 Å.

Differential Thermal Analysis.—We have applied the method of differential thermometry to detect the successive phase changes that occur when lead dioxide is slowly heated from room temperature to 600°, at which temperature red lead is the stable phase.

When the temperature of its surroundings T_e is increased at a constant rate, the temperature T_s of an inert material will also increase steadily. The temperature difference $(T_e - T_s)$ will vary regularly as T_e increases and will be determined by the dimensions and thermal constants of the apparatus. If the material is not inert, then at the onset of, say, an endothermic chemical or physical change in the system the rate of increase of T_s will diminish owing to absorption of heat by the material. When the reaction has progressed to a certain stage the rate of increase of T_s will rise until the original value is regained. Thus the plot of $(T_e - T_s)$ against T_e will show a peak for every endothermic reaction that occurs in the system. By similar reasoning it will be seen that exothermic reactions will give rise to minima in the plot.

This principle was applied as follows. Three silica test-tubes, two containing 2 g. of lead dioxide and one containing 2 g. of alumina (inert in the range 0—600°), were placed in holes drilled symmetrically about the axis of a small cylindrical block furnace (2″ × 2″). The furnace heater was connected to a variable transformer which was activated by a motor geared to change the output voltage from 0 to 270 v in 10 hr. The temperature of the furnace then increased linearly from 20° to about 600° in 10 hr. Throughout the heating chromel–alumel thermocouples (calibrated at the ice-point, the freezing points of tin, lead, and zinc, and at the inversion point of potassium sulphate) were used to measure the temperatures of the inert reference substance and of a sample of lead dioxide, and the difference between these two temperatures. At convenient intervals small samples of the reaction products were withdrawn from the second tube containing lead oxides, and retained for analysis.

Isothermal Decomposition.—Six cylindrical air furnaces (6″ × 1″) were constructed from lengths of brass tubing. The furnace heaters, made by winding each tube with a different length of insulated 30-gauge Nichrome wire, were connected in a series–parallel network and operated from an energy regulator. In this way a set of six different temperatures could be selected by pre-setting the energy regulator and individually controlled to within ±2° of a mean value. Quartz test-tubes, containing about 5 g. of lead dioxide, were placed one in each furnace and heated isothermally for several weeks between 150° and 450°. The products were sampled at intervals by plunging a glass tube of 0·3-mm. diameter in the oxide, and removing a representative plug of the material. These samples were sealed in small test-tubes and retained for analysis. The mean temperature at which each sample decomposed was determined by means of a calibrated chromel–alumel thermocouple. Fluctuations in these temperatures were shown to be less than ±2° by taking frequent readings of a mercury-in-glass thermometer placed with its bulb just above the oxide surface.

Results.

" AnalaR " Lead Dioxide.—(a) *Differential thermometry.* The results of a typical experiment on differential thermal analysis of " AnalaR " lead dioxide are shown in Curve 1, Fig. 1. The ordinate represents the difference between the temperatures of the inert alumina and the reacting lead oxide at any instant; the abscissa represents the temperature of the alumina at the same instant. The three well-defined peaks appearing in this curve indicate that three successive endothermic transitions occur as the temperature of lead dioxide is increased from 20° to above 600° in 10 hr. On repeating the experiment at different rates of heating the

[14] See Bragg, *J. Sci. Instr.*, 1947, **24**, 27.
[15] Gibson, *ibid.*, 1946, **23**, 159.
[16] Nelson and Riley, *Proc. Phys. Soc.*, 1945, **57**, 160.

positions of the maxima and minima on the abscissa were reproduced to within a few degrees, but no better resolution of the three peaks was achieved. In view of the narrow temperature range over which these three transitions occur, this is perhaps not surprising.

The results of a further experiment, which was supplemented by chemical and *X*-ray analysis of the reaction products, are shown in Fig. 2. As the first peak develops, the composition of the lead oxide system changes from $PbO_{1\cdot93}$ to $PbO_{1\cdot6}$, and the characteristic pattern of diffraction lines from lead dioxide is progressively replaced by those characteristic of a new structure. The first peak is undoubtedly due to the conversion of lead dioxide into an intermediate oxide, α-PbO_x, where x is about 1·6. This conclusion was confirmed by preparing, by isothermal decomposition, an oxide of composition $PbO_{1\cdot868}$ and subjecting this material to differential thermal analysis. The results of this experiment are shown in Curve 2, Fig. 1. Only the last two transitions appear.

FIG. 1. *Differential thermometry curves for the decomposition of* (1) *lead dioxide and* (2) α-PbO_x.

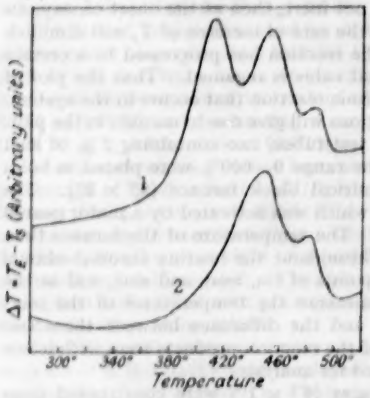
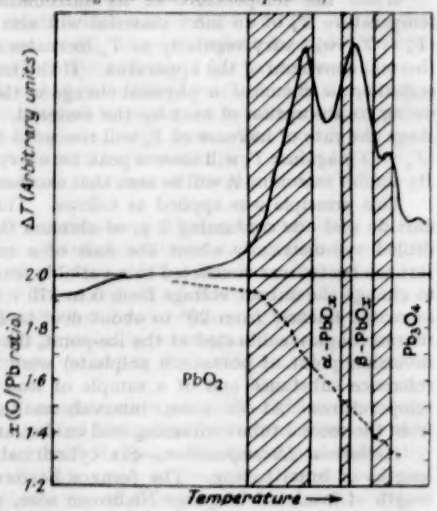


FIG. 2. *Relation between temperature differential and composition of lead oxide.* (*Shaded areas denote regions with two solid phases.*)



The third peak, which develops as the composition of the system changes from about $PbO_{1\cdot4}$ to $PbO_{1\cdot33}$, is associated with the production of red lead from a second intermediate structure.

The origin of the second peak in Curve 1, Fig. 1, is less clear. This peak develops over the composition range from about $PbO_{1\cdot8}$ to about $PbO_{1\cdot6}$, and can be attributed to the formation of a second intermediate oxide β-PbO_x. Its *X*-ray diffraction pattern is, however, so similar to that of α-PbO_x that mixtures of the two structures are difficult to distinguish (see below).

It is probable therefore that the three transitions revealed by differential thermal analysis of lead dioxide are associated with the formation of three intermediate oxides by the successive reactions

$$PbO_2 \longrightarrow \alpha\text{-}PbO_x \text{ where } x \simeq 1\cdot6$$

$$\alpha\text{-}PbO_x \longrightarrow \beta\text{-}PbO_x$$

and

$$\beta\text{-}PbO_x \longrightarrow PbO_{1\cdot33} \text{ where } x \simeq 1\cdot5$$

(b) *Isothermal decomposition.* Those features of our results on the isothermal decomposition of lead dioxide which are relevant to the present discussion are presented in Table 2. This shows how the overall composition of the product PbO_x changes with the heating time at various constant temperatures. The results can be amplified under three headings.

(1) *Decomposition temperatures below* 293° (Fig. 3). At 150° slight decomposition of $PbO_{1\cdot93}$ takes place to an oxide with $x = 1\cdot964 \pm 0\cdot001$ (mean of 4 analyses). (The limits given for x are standard deviations.) At 200° and at 270° the final products have $x = 1\cdot965 \pm 0\cdot002$ and $1\cdot952 \pm 0\cdot003$, respectively. These products are quite stable on prolonged heating (several weeks), and are shown by *X*-ray analysis to contain only lead dioxide.

TABLE 2. *Influence of temperature on the composition of lead oxides.**

Temp.	x in products after heating for t hours: $t = 100$	$t = 1000$	$t = 2200$	Temp.	x in products after heating for t hours: $t = 100$	$t = 1000$	$t = 2200$
200°	1·965	1·965	—	340°	1·568	1·568	—
270	1·952	1·952	—	343	1·568	1·568	1·565
293	1·92	1·74	—	359	1·560	1·540	—
311	1·79	1·565	—	374	1·52	1·38	1·366
327	1·65	1·570	1·570	384	1·42	1·36	—

The values of x were interpolated from graphs of x against t.

(2) *Decomposition temperatures between* **293°** *and* **359°**. Extensive decomposition of lead dioxide sets in at all temperatures above **293°**, and between **293°** and **359°** the composition of the products tends to a limiting value as is shown in Fig. 4. The average value of x for this

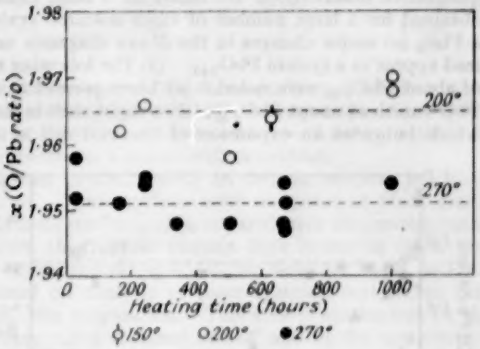


FIG. 3. *Composition of lead dioxide decomposition products at temperatures below 293°.*

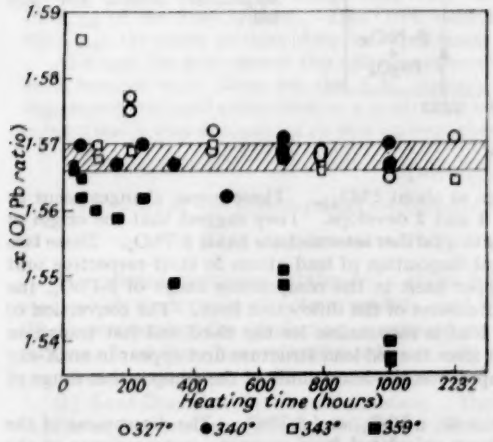


FIG. 4. *Composition of lead dioxide decomposition products at temperatures between 293° and 359°.*

stable oxide (based on 26 values obtained at temperatures from 311° to 343°) is found to be $1{\cdot}568_5$ with a standard deviation of $0{\cdot}002_3$. This is in excellent agreement with the value of x for Pb_7O_{11}, *i.e.*, 1·571, and is much less than its value for Pb_6O_8. *X*-Ray analysis of the products formed from lead dioxide in this temperature range and represented in Fig. 4 showed the presence of a single phase α-PbO_2. In the initial products of decomposition of lead dioxide, diffraction lines, characteristic of this oxide, first became visible in a system $PbO_{1\cdot 935}$. If it be assumed that 5% of this phase is required to give visible *X*-ray diffraction lines, then the lower limit of composition for the lead dioxide structure appears to be $PbO_{1\cdot 95}$.

As the composition of the products passes from $PbO_{1\cdot 935}$ to $PbO_{1\cdot 634}$ the diffraction lines of the lead dioxide structure decrease in intensity as the lines of the new phase α-PbO_2 become more intense. The system $PbO_{1\cdot 634}$ still exhibits very faint lines from the lead dioxide structure; if it be assumed that 5% of lead dioxide is still present in this system, then the upper limit of

composition for α-PbO_x is $PbO_{1\cdot 43}$. The formation of α-PbO_x from lead dioxide is clearly responsible for the first of the three successive transitions observed in the experiments on differential thermal analysis.

(3) *Decomposition temperatures above* 359° (Fig. 5). The oxide α-PbO_x is unstable at 359° but even after 1000 hours' heating at this temperature the composition of the product is only $PbO_{1\cdot 558}$ (Fig. 4). At 374° and 384° more extensive decomposition occurs. No arrests in the composition–time curves were noted but the colour of the products changed progressively from black ($PbO_{1\cdot 55}$) through maroon to red ($PbO_{1\cdot 34}$).

Since the second and the third transition shown in Figs. 1 and 2 occur within this composition range, their origins can only be inferred from an interpretation of the *X*-ray diffraction patterns obtained for these coloured systems.

X-Ray Analysis of Coloured Lead Oxide Systems between $PbO_{1\cdot 57}$ *and* $PbO_{1\cdot 33}$.—The following qualitative observations are based on a close examination of the *X*-ray diffraction patterns obtained for a large number of these coloured systems. (1) On progressive decomposition of α-PbO_x no major changes in the *X*-ray diagrams are observed until lines characteristic of red lead appear in a system $PbO_{1\cdot 41}$. (2) The following minor changes which set in at a composition of about $PbO_{1\cdot 50}$ were noted: (*a*) Lines present at high Bragg angles in the *X*-ray diagram of PbO vanish at about $PbO_{1\cdot 50}$; (*b*) a slight shift in line position towards lower angles is observed which indicates an expansion of the unit cell at about $PbO_{1\cdot 50}$ (Table 2); (*c*) the relative

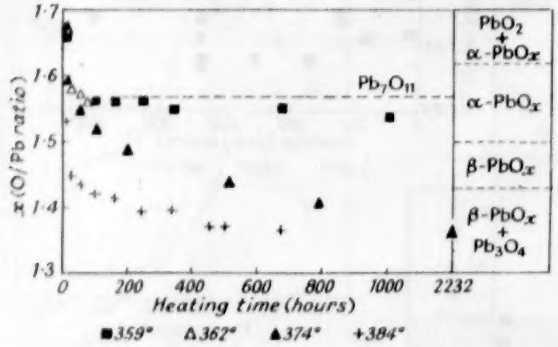


FIG. 5. *Composition of lead dioxide decomposition products at temperatures between* 359° *and* 384°.

intensities of certain diffraction lines change at about $PbO_{1\cdot 50}$. These minor changes occur as the second well-defined transition in Figs. 1 and 2 develops. They suggest that the origin of this transition is the conversion of α-PbO_x into a further intermediate oxide β-PbO_x. These two structures correspond to an almost identical disposition of lead atoms in their respective unit cells. It is therefore difficult to fix an upper limit to the composition range of β-PbO_x, the difficulty being further increased by the diffuseness of the diffraction lines. The conversion of β-PbO_x (where x is close to 1·50) into red lead is responsible for the third and last transition recorded in Figs. 1 and 2. Diffraction lines from the red lead structure first appear in an *X*-ray photograph of $PbO_{1\cdot 41}$, so that at this composition the lower limit of the composition range of β-PbO_x has been reached.

Dimensions of the Unit Cells of Lead Dioxide, α-PbO_x, *and* β-PbO_x.—The dimensions of the tetragonal unit cell of lead dioxide have been calculated from accurate measurements of the relevant line positions in *X*-ray photographs of systems containing various amounts of its decomposition product, α-PbO_x. With the exception of certain weak lines, the diffraction patterns arising from the intermediate oxides were satisfactorily indexed—α-PbO_x as a body-centred tetragonal structure, and β-PbO_x as a body-centred cubic structure. The unit cell dimensions of these three oxides are given in Table 3.

In systems where x lies between 1·961 and 1·801, the values of the parameters of the lead dioxide unit cell do not vary by more than 1 part in 5000 (the experimental accuracy) from the mean values $a_0 = 4\cdot 957_8$, $c_0 = 3\cdot 387_5$, $c/a = 0\cdot 6833$. These results support the argument that the lead dioxide structure persists over a very narrow range of compositions. The diffraction lines arising from the lower oxide are more diffuse than the lead dioxide lines and this limits the accuracy of their parameters to less than 1 part in 1000. The diffuseness of these lines is possibly due to comminution of the individual granules in the process of decomposition.

TABLE 3.

x	Phases present	Phase indexed	a_0	c_0	c/a
1·973	PbO_2	PbO_2	$4·953_2$	$3·386_0$	0·6836
1·961	,,		$4·957_1$	$3·386_8$	0·6832
1·954	,,		$4·957_8$	$3·387_5$	0·6833
1·940	,,		$4·958_7$	$3·388_0$	0·6832
1·935	,, + α-PbO_x		$4·957_4$	$3·387_4$	0·6833
1·879	,, + α-PbO_x		$4·957_5$	$3·387_4$	0·6833
1·860	,, + α-PbO_x		$4·956_1$	$3·386_5$	0·6833
1·801	,, + α-PbO_x		$4·958_3$	$3·389_0$	0·6835
1·650	,, + α-PbO_x		$4·95_7$	$3·38_4$	$0·682_7$
1·801	PbO_2 + α-PbO_x	α-PbO_x	$5·41_3$	$5·43_0$	1·004
1·650	,, + α-PbO_x		$5·41_6$	$5·49_1$	1·014
1·572	α-PbO_x		$5·41_6$	$5·49_0$	1·015
1·546	α-PbO_x		$5·41_5$	$5·49_0$	1·016
1·437	β-PbO_x	β-PbO_x	5·491	—	1·000
1·406	β-PbO_x + Pb_3O_4		5·479	—	1·000

Electrolytic Lead Dioxide.—For purposes of comparison the decomposition of an electrolytic preparation of lead dioxide (see p. 726) was carried out. At 150° decomposition takes place to an oxide with $x = 1·940 \pm 0·001$, and at 250° to an oxide with $x = 1·940 \pm 0·003$. At 293°, 327°, 343°, and 374° extensive decomposition to a lower oxide is evident.

Distinct heterogeneity was observed when products with an oxygen content less than $PbO_{1·70}$ were examined under the microscope. These systems were composed of black grains dotted with tiny patches of a red oxide. If these products are compared with the corresponding systems derived from the A.R. lead dioxide, they should contain dark brown or black lead dioxide and black α-PbO_x. The presence of this red oxide, which can be either Pb_3O_4 or PbO, contributes to the large variability obtained on analysis of these systems, and shows that equilibrium conditions are unattainable with this preparation. This view is emphasised by the absence of any arrest in the composition–time curve obtained at 343° and by the composition $PbO_{1·846}$ of the final product. This O/Pb ratio is significantly less than that of α-PbO_x (or $PbO_{1·868}$), the stable product of earlier experiments at this temperature.

Although the grain size of this dioxide appeared to be quite large, the *X*-ray diffraction lines were broader than those for the A.R. preparation. This material is therefore either an agglomerate of small crystallites or a mixture of both large and small crystallites. Its physical heterogeneity may account for its non-uniform chemical reactivity.

DISCUSSION

The results of this investigation are consistent with the reaction scheme:

Lead dioxide ⟶ α-PbO_x ⟶ β-PbO_x ⟶ red lead.

The present discussion is intended: (1) to determine the probable range of composition over which each oxide structure persists, and to summarise their structural parameters; (2) to re-examine the conflicting results of previous work on these systems within the framework of the above reaction scheme; (3) to assess the importance of any evidence that does not conform to this reaction scheme.

(1) *Lead Dioxide.*—(a) *Crystal structure.* The composition of the A.R. lead dioxide used can be represented by $PbO_{1·98}$,$0·04H_2O$. *X*-Ray analysis confirms that it has a body-centred tetragonal structure. The unit cell dimensions of the unheated dioxide, and of the dioxide present in partly decomposed systems, are compared in Table 4 with values determined by Byström [9] and by Katz.[10]

TABLE 4. *Lattice parameters* (Å) *of lead dioxide*; (a) *unheated specimens*; (b) *partly decomposed systems.*

Authors	x	Pretreatment	a_0	c_0	c/a
Byström	1·988	(*a*)	4·952	3·385	0·6835
	1·96	(*b*)	4·960	3·390	0·6834
Katz	1·99	(*a*)	4·955	—	0·6827
	1·82	(*b*)	4·958	—	0·6823
This work	1·98	(*a*)	4·953	3·386	0·6836
	1·96—1·78	(*b*)	4·958	3·388	0·6833

Byström's values, originally reported in *k*X units (personal communication), have been transformed into Å units. Our values are in excellent agreement with his, and all three sets of figures suggest that the parameters a_0 and c_0 both increase by about 0·1% when lead dioxide is heated and partly decomposed.

(b) *Decomposition temperature of lead dioxide in air.* Extensive decomposition of lead dioxide in air to a new oxide phase α-PbO_x occurred at temperatures above 293°. Since the dioxide structure was stable at temperatures up to at least 270°, its decomposition temperature in air must be 280° ± 10°. This value agrees well with those reported earlier, *viz.*, 290°,[17] 280°,[1b] 293° for an electrolytic oxide and 314° for a precipitated oxide,[18] and 280°.[2]

At temperatures below 293° a small but definite decrease in the O/Pb ratio of our sample of lead dioxide was recorded. At 150° the ratio changed from 1·973 to 1·964, at 200° to 1·965, at 270° to 1·952, and these values were unchanged by further prolonged heating. In these low-temperature reaction products no other phase than lead dioxide was detected, and high-angle α-doublet lines, which were not resolved in *X*-ray diffraction photographs of the original dioxide, were sharp and perfectly resolved. This suggests that the imperfect structure of the original sample was annealed (with slight loss of oxygen) by prolonged heating at temperatures below 280°. This observation may explain why Reinders and Hamburger [19] could not reproduce the small pressures of oxygen developed when lead dioxide was heated *in vacuo* at these low temperatures. In this connection, we could not measure the dissociation pressure of lead dioxide at 280°. Equilibrium was not achieved even after 400 hr., and after the oxygen evolved had been pumped off, the pressure–time in a second decomposition experiment always lay below the initial curve.

(c) *Composition limits of the lead dioxide structure.* All preparations of lead dioxide have had an O/Pb ratio approximating to but always less than 2, its upper limit, and lines due to second phase, α-PbO_x, were just visible in an *X*-ray diffraction photograph of a decomposition product, $PbO_{1·935}$. This critical value of the O/Pb ratio must be less than that at which the lead dioxide structure becomes unstable, for the first traces of α-PbO_x to be formed will not be detected by *X*-ray methods. If we arbitrarily assume that at least a 5% conversion of the dioxide into α-PbO_x is necessary for the latter phase to be detected, then the lower limit of composition for lead dioxide is close to $PbO_{1·95}$ (if it is assumed that α-PbO_x is Pb_7O_{11}). Further, the lattice parameters of lead dioxide increase slightly in the initial stages of decomposition and then remain constant as an increasing fraction of the dioxide is converted into α-PbO_x. These facts provide supporting evidence for the conclusion that the lead dioxide structure persists over a very narrow range of composition. Byström [9] and Clark and Rowan [7] are of the same opinion. Katz,[10] however, reported the lower limit of composition for lead dioxide to be $PbO_{1·875}$, and Eberius and Le Blanc [12] state that this limit is only reached at $PbO_{1·66}$.

Katz based his value on microphotometer measurements of the intensities of lines due to lead dioxide and α-PbO_x in *X*-ray diffraction photographs of two systems; (1) a system $PbO_{1·82}$, produced by decomposition of lead dioxide, and (2) a synthetic mixture, $PbO_{1·794}$, consisting of 90% by weight of $PbO_{1·82}$ and 10% of α-PbO_x ($x = 1·57$), prepared by complete decomposition of lead dioxide at an appropriate temperature. The ratios of the intensities of selected lines from each phase were calculated for the two systems and plotted against x. A linear extrapolation to zero ratio of line intensities (*i.e.*, no α-PbO_x present) then gave $PbO_{1·875}$ as the lower limit of composition for the dioxide. This procedure is open to criticism, for it assumes that the α-PbO_x formed in the initial stages of reaction is as readily detected in *X*-ray analysis as the products of complete decomposition. Clearly, if the first traces of α-PbO_x arise preferentially from the smallest grains of lead dioxide, or if the phase change proceeds in each grain at an advancing phase boundary, or if sintering of completely decomposed grains occurs, then this assumption is not valid and the derived composition limit must be too low.

[17] Hempel and Schubert, *Z. Electrochem.*, 1912, **18**, 729.
[18] Krustinsons, *ibid.*, 1934, **40**, 246; 1937, **43**, 65.
[19] Reinders and Hamburger, *Z. anorg. Chem.*, 1914, **89**, 71.

Eberius and Le Blanc's results cannot be reconciled with the view that the lead dioxide structure exists solely in the range of composition extending from PbO_2 down to about $PbO_{1\cdot95}$. It may be possible, however, for the structure to persist in metastable equilibrium at lower O/Pb ratios.

(2) α-PbO_x.—(a) *Composition.* Lead dioxide decomposed in air at temperatures between 293° and 359°, and was converted into a stable black oxide of characteristic structure. Chemical analysis showed that the final product of decomposition (at 293°, 311°, 327°, and 340°) had a constant O/Pb ratio of $1\cdot568_5$. This value is close to that for the empirical formula Pb_7O_{11} (1·571) which was first assigned to α-PbO_x by Holtermann and Laffitte.[8a]

Some authors consider that α-PbO_x is Pb_5O_8 ($x = 1\cdot600$); others support the formula Pb_2O_3. The evidence for these formulæ must be closely examined if a definite composition is to be assigned to α-PbO_x.

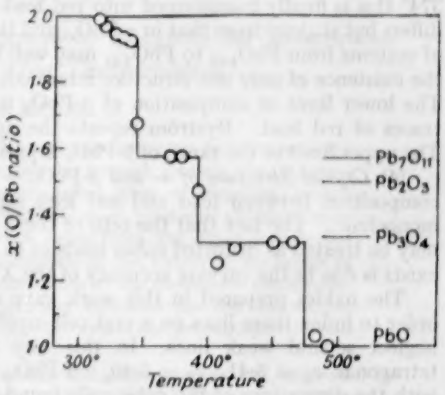


FIG. 6. *Decomposition of lead dioxide from data of Carnelley and Walker.*[15]

Byström prepared single crystals of α-PbO_x which were shown to have a formula $PbO_{1\cdot556}$. This composition provides no clear proof that α-PbO_x is either Pb_5O_8 or Pb_7O_{11}. Clark and Rowan [7] call this intermediate oxide Pb_5O_8, but again there is little evidence in favour of this particular formula. Thus, when their results for isothermal decompsition of lead dioxide are plotted, the composition–time curves show no portion parallel to the time axis. This is not surprising since only short times of decomposition were used, and no experiments were reported for the temperature range 300—350°. Fischer and Ploetze [6] also favour Pb_5O_8, but again their heating times were too short to verify that an equilibrium composition had been reached. In our experiments equilibrium conditions were achieved and, at several temperatures, the final product had a constant composition, $PbO_{1\cdot568}$. The classical evidence of the composition of α-PbO_x is therefore consistent with this phase's being Pb_7O_{11} ($x = 1\cdot57$) but a final decision must await a complete determination of its structure.

A re-examination of the results quoted by Carnelley and Walker [15] and by Baroni [4] in support of the formula Pb_2O_3, shows that the evidence suggests more convincingly a composition Pb_7O_{11} for α-PbO_x. This conclusion is immediately obvious from Fig. 6, which is a decomposition curve for lead dioxide, recalculated from the results of Carnelley and Walker by assuming that the final reaction product was PbO. Baroni's evidence for Pb_2O_3 is invalidated by an arithmetical error in calculating the formula of an intermediate oxide formed from PbO and containing 11·35% of active oxygen. Such a system corresponds to $PbO_{1\cdot66}$ and not to $PbO_{1\cdot50}$. Thus the "Pb_2O_3" of Baroni is a higher oxide, and his results on the decomposition of lead dioxide suggest that it could be Pb_7O_{11} or Pb_5O_8.

(b) *Composition limits of the oxide* α-PbO_x. *X*-Ray diffraction analysis of the products of decomposition of A.R. lead dioxide showed that lines from α-PbO_x gradually replaced those from the lead dioxide structure. The system $PbO_{1\cdot636}$ contained very faint lines due to lead dioxide, *i.e.*, the upper limit of the O/Pb ratio for α-PbO_x is certainly less than

1·636. On the arbitrary assumption that this system still contains 5% of lead dioxide, the upper limit of this ratio for α-PbO_x is 1·62. This figure is lower than that given by Byström ($x = 1·66 \pm 0·02$) but equal to that calculated from Clark and Rowan's results. Because of the similarity between the structures of α-PbO_x and its first decomposition product β-PbO_x, the lower limit of composition of the former oxide cannot be clearly defined by *X*-ray methods. This limit is probably close to $PbO_{1·5}$, *i.e.*, the value given by Byström. Thus the results of *X*-ray analysis show that α-PbO_x is probably restricted to the range from $PbO_{1·62}$ to $PbO_{1·5}$, and this range may indeed be narrower.

(c) *Decomposition temperature of* α-PbO_x *in air.* α-PbO_x is stable at 343° but loses oxygen on prolonged heating in air at 359°. The decomposition temperature of this oxide is therefore 351° ± 8°, a value that agrees with estimates given by Carnelley and Walker (360°), by Moles and Vitoria (366°), and by Byström (350°).

(3) β-PbO_x.—At temperatures above 359°, α-PbO_x is first converted into β-PbO_x and at 374° this is finally transformed into red lead. The arrangement of lead atoms in β-PbO_x differs but slightly from that in α-PbO_x, and the minor changes in *X*-ray diffraction patterns of systems from $PbO_{1·55}$ to $PbO_{1·41}$ may well have been overlooked by workers who report the existence of only one structure intermediate in composition between PbO_2 and Pb_3O_4. The lower limit of composition of β-PbO_x is close to $PbO_{1·42}$, for this system contained traces of red lead. Byström reports the appearance of red lead in an oxide, $PbO_{1·47}$. The upper limit to the range of β-PbO_x is probably close to $PbO_{1·50}$.

(4) *Crystal Structure of* α- *and* β-PbO_x.—The unit cells for the oxides intermediate in composition between lead and red lead reported in the literature vary from cubic to monoclinic. The fact that the cells of these oxides, as determined by Byström and Katz, may be treated as distorted cubes leads us to believe that a large part of the confusion that exists is due to the varying accuracy of the *X*-ray methods used.

The oxides prepared in this work gave diffraction lines that were quite diffuse. In order to index these lines on a unit cell involving only two parameters it was necessary to neglect several weak lines. In this way the following cells were derived: α-PbO_x, tetragonal, $a_0 = 5·41_6$, $c_0 = 5·49_6$; β-PbO_x, cubic, $a_0 = 5·48_5$. These may be compared with the dimensions of the cubic cells found by Holtermann for Pb_7O_{11}, $a_0 = 5·4$, and by Baroni for the oxide "Pb_2O_3" (see p. 733), $a_0 = 5·50$.

Clark and Rowan found the unit cell of Pb_5O_8 to be tetragonal with $a_0 = 5·508$, $c_0 = 5·460$. This result is inconsistent with our own since a_0/c_0 is greater than unity, whereas our value for α-PbO_x is less than unity. Since these figures must refer to the same oxide, we have re-examined Clark and Rowan's data and find that their d spacings may be indexed satisfactorily on the basis of a unit cell with $a_0 = 5·441$, $c_0 = 5·513$. This is in better agreement with our values.

The most accurate *X*-ray examination of the lead oxides has been carried out by Byström and by Katz. Byström found the following unit cells for the intermediate oxides: α-PbO_x, $1·66 > x > 1·50$, monoclinic, $a_0 = 3·86$, $b_0 = 5·41$, $c_0 = 3·83$, $\beta = 88·68°$; β-PbO_x, $1·50 > x > 1·47$, orthorhombic, $a_0 = 3·89$, $b_0 = 5·49$, $c_0 = 3·82$. The relationship between these unit cells and those referred to previously may be easily seen by a simple transformation involving rotation about the b axis to give a new cell whose sides are the diagonals of the original cell, *viz.*, α-PbO_x, $a' = 5·37$, $b' = 5·41$, $c' = 5·50$, $\beta' \simeq 90°$; β-PbO_x, $a' = 5·45$, $b' = 4·49$, $c' = 5·45$, $\beta' \simeq 90°$.

Katz employed a technique for determining accurately the position of the low-angle lines on the *X*-ray diffraction patterns obtained with oxides prepared both by decomposition of lead dioxide and by oxidation of lead monoxide. He found that between $PbO_{1·33}$ and $PbO_{1·57}$ a large number of solid solutions exist with an orthorhombic, pseudo-cubic structure. These solid solutions can be distinguished only by their deviations from cubic symmetry. At the limits of composition these solutions are disordered but they can become ordered around the composition Pb_2O_3 provided that they are prepared by the slow oxidation of lower oxides. In the range of composition $1·33 < x < 1·55$ these oxides can be oxidised or reduced in a continuous manner. If, in the course of oxidation, the limit $x = 1·55$ is exceeded, on subsequent reduction the composition jumps from $x = 1·55$ to $x = 1·41$.

It is probable that these treatments are an oversimplification. Thus, the weak lines neglected by us in indexing our diffraction patterns cannot be indexed on either the Katz or the Byström unit cell. To accommodate weak lines, Byström had occasion to double the a_0 axis and to treble the c_0 axis for α-PbO_x, and to double both these axes for β-PbO_x. Again, the lower limit of β-PbO_x in our experiments occurred at about $x = 1{\cdot}42$ and was certainly not as low as 1·33, the value reported by Katz.

The authors thank Prof. G. D. Preston for his interest and for providing facilities for *X*-ray analysis, and Prof. W. F. K. Wynne-Jones and Dr. H. R. Thirsk for helpful discussions. One of them (G. B.) is indebted to the Department of Scientific and Industrial Research for a grant.

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146. *The Deuteration and Exchange of Ethylene on Evaporated Metal Catalysts at Low Temperatures.*

By Charles Kemball.

Measurements have been made by a mass-spectrometric technique of the amounts of the various deutero-compounds formed during the reaction between ethylene and deuterium on evaporated films of tungsten, nickel, rhodium, and iron at −100°. The distribution of products obtained over tungsten films differed substantially from those from the other metals but was in accord with the behaviour of tungsten in the catalytic exchange of ethane and deuterium. The relative efficiencies of the metals for the deuteration of ethylene at −100° gave supporting evidence for the correlation between activity for hydrogenation at 0° and the percentage *d*-bond character of the intermetallic bonds.

The results provided new evidence for the close connection between exchange and deuteration of ethylene, and a general theory has been formulated for the calculation of the distribution of initial products in terms of four fundamental parameters associated with the adsorbed species in this reaction. Good agreement was obtained between calculated and observed distributions. Although the general theory was not based on any particular mechanism for the reaction, a method has been suggested by which it may be used to assess the part played by different mechanisms.

A recent investigation [1] has shown that there is a great variation in the catalytic activity of different transition metals for the exchange reaction between ethane and deuterium. Furthermore, there were differences in the initial products obtained; tungsten, molybdenum, and tantalum produced [$^2H_1$]ethane as the major initial product because a simple exchange mechanism (replacement of one hydrogen atom at a time) was operating. On rhodium and palladium a multiple exchange mechanism predominated and gave [$^2H_6$]ethane as the most abundant initial product. The present work was undertaken to see if there were corresponding differences in the amounts of olefin-exchange and in the pattern of the deuteroethanes when certain of these metals were used as catalysts for the ethylene–deuterium reaction.

The only investigations in which complete analyses of all the deutero-ethylenes and -ethanes formed in this reaction have been reported were those of Turkevich *et al.*[2] who worked with a nickel-filament catalyst at 90°, and that of Wilson *et al.*[3] who used a commercial nickel catalyst supported on kieselguhr between −50° and 50°. The importance of these complete analyses for a better understanding of the mechanisms operating in the hydrogenation and exchange of olefins has been stressed by Wilson *et al.*[3]

[1] Anderson and Kemball, *Proc. Roy. Soc.*, 1954, *A*, **223**, 361.
[2] Turkevich, Bonner, Schissler, and Irsa, *Discuss. Faraday Soc.*, 1950, **8**, 352; Turkevich, Schissler, and Irsa, *J. Phys. Colloid Chem.*, 1951, **55**, 1078.
[3] Wilson, Otvos, Stevenson, and Wagner, *Ind. Eng. Chem.*, 1953, **45**, 1480.

and also by Bond.[4] Keii [5] has developed theoretical equations for the initial-product distributions based on the reaction mechanism favoured by Horiuti [6] and has shown that they give results in general agreement with the observations of Turkevich *et al.*[2]

A low temperature (*ca.* −100°) was chosen for the present experiments, partly in order that the rates of reaction should be low enough to allow determination of the initial distribution of products, and partly for the purpose of comparing the efficiencies of the different metals for deuteration at a temperature substantially different from that used by Beeck.[7]

Experimental

The preparation of the metallic films, the catalytic apparatus, and the manner in which the reacting gases were allowed to bleed into the mass spectrometer have been described.[8] Ethylene was obtained from a cylinder and purified by distillation from cold traps. Mass-spectrometric analysis showed that it contained less than 0·5% of ethane. In most of the experiments, 2·7 mm. of ethylene and 8·1 mm. of deuterium, after passage through a trap at −78° to condense mercury vapour, were admitted to the reaction vessel at approximately −120°. The volume of the reaction vessel was 180 ml. and the charge of hydrocarbon was estimated to be $2{\cdot}4 \times 10^{19}$ molecules.

Temperature control proved to be difficult. A large Dewar vessel containing the eutectic mixture of ethyl bromide, 45% (by vol.), trichloroethylene, 21%, chloroform, 20%, and dichloroethylene, 14%, was used. This mixture freezes at −139° but it was possible to keep the temperature steady within 2—3° at approximately −100° for periods of 30—45 min. by adding small quantities of liquid air to the liquid in the Dewar vessel. Temperatures were measured by a calibrated thermocouple. After a few minutes had been allowed for the gas mixture to flow into the mass spectrometer with the reaction vessel at −120°, the temperature was adjusted to −100° and readings were taken.

During each experiment, sets of readings were taken alternately of (*a*) the peaks corresponding to masses 28—32 with 11·0 v for the ionising electrons in the mass spectrometer, and of (*b*) the peaks corresponding to masses 28—36 with 13·4 v for the electrons. By interpolation, values for both sets were obtained at the same time and were corrected for the heavy carbon and deuterium occurring naturally. The fragmentation of ethylene was negligible at both voltages, but with " ethane " * ions corresponding to the loss of one or two " hydrogen " atoms occurred at both voltages. Correction to peaks of lower mass than the parent ion for fragmentation of the ethanes for mass spectra with 13·4 v on the electrons were based on the data in Table 1. In compiling this Table the fragmentations of non-deuterated ethane and

Table 1. *Corrections for fragmentation to peaks corresponding to masses* X − n, *where* X *is the parent mass for ethanes with* 13·4-v *acceleration on the ionising electrons.*

X	n = 1	2	3	4	X	n = 1	2	3	4
36	—	0·12	—	2·00	32	0·08	1·18	0·66	0·18
35	0·02	0·10	0·74	1·26	31	0·10	1·42	0·60	—
34	0·04	0·26	1·11	0·71	30	0·12	1·75	—	—
33	0·06	0·53	1·20	0·33					

[$^2H_6$]ethane were determined experimentally. The small corrections for ions formed by the loss of one " hydrogen " atom from the other ethanes were estimated by interpolation. The fragmentation for the loss of two " hydrogen " atoms for the other ethanes was assumed to occur to the same total extent as with [$^2H_6$]ethane, and the correction factors were determined by assuming that the *a priori* chance of losing a hydrogen atom * was 1·17 times the chance of losing a deuterium atom. As the final reaction product on tungsten films was mainly

* Throughout this paper, " ethane " and " hydrogen " are used as generic terms irrespective of isotopic content.

[4] Bond, *Quart. Rev.*, 1954, **8**, 279.
[5] Keii, *J. Res. Inst. Catalysis, Hokkaido Univ.*, 1953, **3**, 36; *J. Chem. Phys.*, 1954, **22**, 144.
[6] Horiuti, *Catalyst*, 1948, **2**, 1.
[7] Beeck, *Discuss. Faraday Soc.*, 1950, **8**, 118.
[8] Kemball, *Proc. Roy. Soc.*, 1951, *A*, **207**, 539; 1952, *A*, **214**, 413.
[9] Turkevich, Friedman, Solomon, and Wrightson, *J. Amer. Chem. Soc.*, 1948, **70**, 2638.

$[^2H_2]$ethane, it was possible to check the figures used for the fragmentation of that compound. The fragmentation of the ethanes at the lower electron voltage was also determined; the values were approximately half as much as those at the higher voltage.

The complete analysis of the percentages of all five ethylenes and all seven ethanes was possible because the sensitivity of the peak heights for ethanes increased 30-fold between the two voltages whereas the increase for the ethylenes was only 8-fold. In working up the results, corrections for fragmentation were applied to the values for the peaks corresponding to mass 36 down to mass 32. Corrected values of the peak corresponding to mass 32 were thus obtained at both electron voltages, and the solving of a simple pair of simultaneous equations gave the proportions of these due to $[^2H_2]$ethane and $[^2H_4]$ethylene. Corrections to the values of peaks corresponding to mass 31 were then made, and the process continued down to mass 28. The relative sensitivities for ethylene and ethane at the higher voltage were known and therefore it was possible to express the amounts of the five ethylenes and the seven ethanes as percentages of the total C_2 hydrocarbon present.

This procedure is not claimed to be of great accuracy—the greatest uncertainties were in the evaluation of the $[^2H_0]$- and $[^2H_1]$-ethanes and the $[^2H_3]$- and $[^2H_4]$-ethylenes owing to small changes in relative sensitivity if the voltage of the electrons altered. Nevertheless, the method enabled a complete analysis for the twelve C_2 hydrocarbons to be made from readings obtained in a few minutes on a simple mass spectrometer. The analyses of the ethanes obtained at the end of each run were more accurate because two or three complete sets of readings were taken and there were no contributions from ethylenes.

Results

The amounts of the various ethylenes and ethanes formed during experiments on nickel, iron, rhodium, and tungsten are shown in Figs. 1—4. The plots of total percentage of ethanes against time (Fig. 5) showed that the rates of deuteration were constant throughout each run, and these plots were used to decide the position of the final analyses corresponding to 100% ethanes on Figs. 1—4. Because of the greater accuracy of the final analyses, more weight was given to these points in drawing the curves in Figs. 1—4.

Although the percentages of the deuteroethylenes of necessity varied with time in a complicated manner, it was possible to reduce the values to a linear relation from which the rate of exchange of ethylene could be determined. A quantity ϕ was defined by

$$\phi = w + 2x + 3y + 4z \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where w, x, y, z represented the percentages of ethylene present at any stage as $[^2H_1]$- to $[^2H_4]$-ethylene. Plotting of results according to the integrated form of the equation,

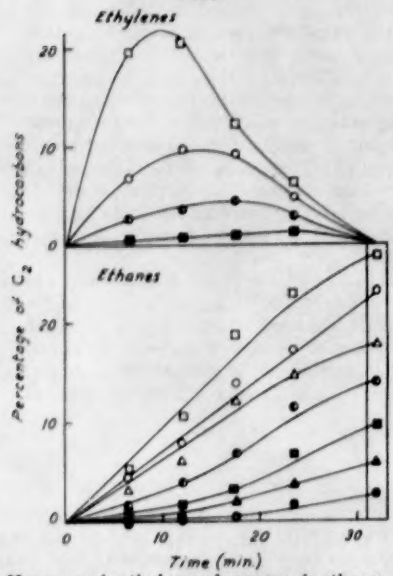
$$d\phi/dt = k\,(\phi_\infty - \phi)/\phi_\infty \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where t is time and k the initial rate of entry of deuterium atoms into 100 ethylene molecules, gave the straight lines shown in Fig. 6. As no appreciable quantities of hydrogen were returned to the gas phase (see below) to dilute the deuterium, it was justifiable to assume a value of 400 for ϕ_∞, the ultimate value of ϕ, corresponding to completely deuterated ethylene, that would have been reached had the ethylenes not been removed by deuteration. With tungsten, where the olefin-exchange was much less, the rate was found by a direct plot against time of the percentage of ethylene present as $[^2H_1]$ethylene.

The final percentages of the various ethanes obtained under different conditions, and the mean deuterium content of the ethanes, are shown in Table 2 together with corresponding results from earlier work. The proportions of HD formed during the reactions on nickel, iron, and rhodium were determined by examination of the peaks corresponding to masses 3 and 4, a sufficiently low electron voltage being used to avoid contributions due to fragmentation of the ethanes. With nickel and iron, some 1·5% of HD was formed, but with rhodium, 5% was formed. The presence of these small amounts of hydrogen in the deuterium should have been balanced by a slight excess of deuterium in the ethanes over and above the mean number of two deuterium atoms per ethane molecule. The expected values of M, based on the amount of HD present, were 2·03 for iron and nickel and 2·10 for rhodium.

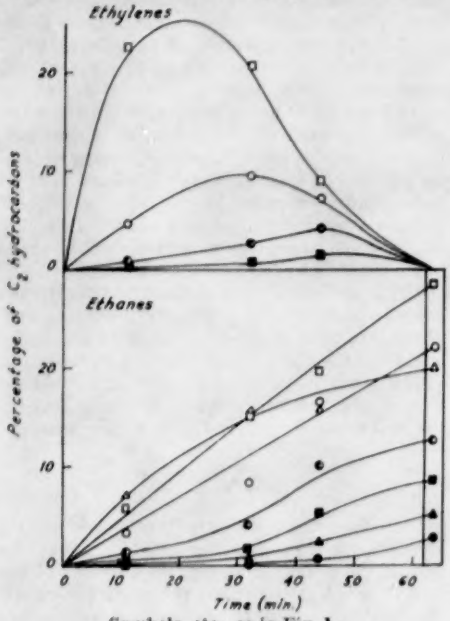
The rates of deuteration and olefin-exchange are given in Table 3 together with values of S, the coefficient of spread of the ethanes ultimately formed; S was a measure of the extent to

FIG. 1. *Reaction on 13·6 mg. of nickel at −100°.*



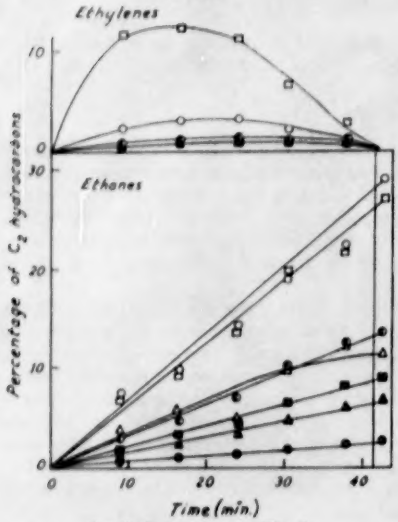
Upper graph, ethylenes; lower graph, ethanes. Final percentages of ethanes in frame. Symbols △, □, ○ ◐, ■, ▲ and ● represent compounds containing from 0 to 6 deuterium atoms.

FIG. 2. *Reaction on 10·2 mg. of iron at −100°.*



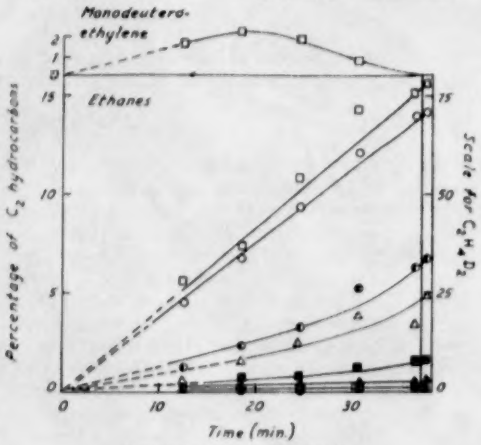
Symbols, etc., as in Fig. 1.

FIG. 3. *Reaction on 1·3 mg. of rhodium at −104°.*



Symbols, etc., as in Fig. 1.

FIG. 4. *Reaction on 7·8 mg. of tungsten at −99°.*



Symbols, etc., as in Fig. 1.

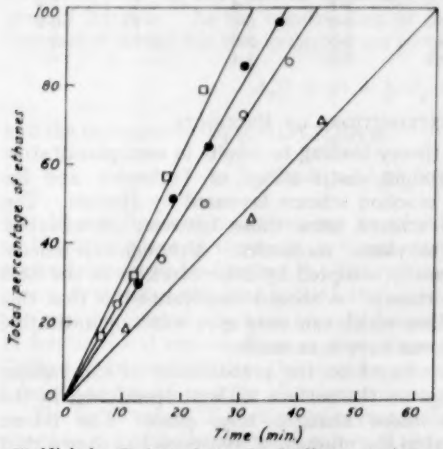
which the composition of the ethanes deviated from 100% [$^3H_2$]ethane and ranged over all values of deuterium content and was defined by

$$S = \sum_n (|n - 2|d_n)/d_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where d_n represents the percentage of the ethane with n deuterium atoms.

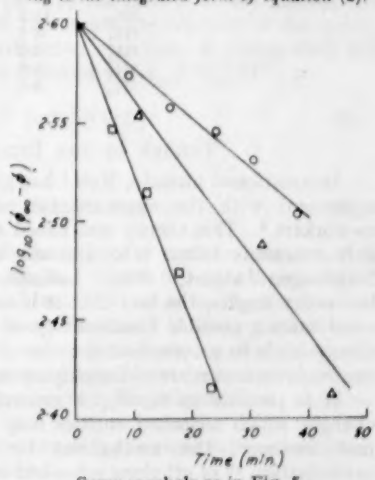
Although the temperature control was not sufficiently good to allow accurate determination of activation energies and pressure dependencies, some rough observations were noted. Ethylene-exchange and deuteration on tungsten had an activation energy of 5—6 kcal./mole between −120° and −100°, and both reactions on the other three metals had a value of 7 kcal./mole. On nickel, both reaction rates were independent of ethylene pressure and were proportional to the square root of the deuterium pressure. An experiment with ethylene alone

FIG. 5. *Total ethanes versus time for experiments in Figs. 1—4.*



□, Nickel; ●, tungsten; ○, rhodium; △, iron.

FIG. 6 *Plots of exchange of ethylene according to the integrated form of equation* (2).



Same symbols as in Fig. 5.

TABLE 2. *Percentages of various ethanes in final products and the mean deuterium number* (*M*) *of the ethanes.*

Ratio $D_2 : C_2H_4$	Catalyst	Temp.	$^3H_0$	$^3H_1$	$^3H_2$	$^3H_3$	$^3H_4$	$^3H_5$	$^3H_6$	*M*
3 : 1	Rh	−104°	11·5	27·2	29·1	13·7	9·1	6·8	2·6	2·10
3 : 1	Fe	−100	20·1	28·4	22·1	12·7	8·6	5·2	2·9	1·89
3 : 1	W	− 99	4·8	15·5	70·5	6·7	1·6	0·5	0·14	1·89
3 : 1	Ni	−100	17·9	26·8	23·2	14·0	9·6	5·9	2·6	1·99
9 : 1	Ni	− 92	12·4	29·9	25·4	14·3	9·7	5·9	2·4	2·06
9 : 3	Ni	− 81	17·1	30·5	20·7	13·8	9·4	6·2	2·3	1·96
10 : 1	Ni *	− 50	17·8	25·6	27·4	16·1	7·8	3·6	1·5	1·87
2 : 1	Ni †	90	8·0	29·5	25·1	16·7	11·8	6·9	2·0	2·24
Random distribution			8·8	26·3	32·9	22·0	8·2	1·7	0·14	2·00

* Supported nickel catalyst.[3] † Nickel wire.[2]

TABLE 3. *Rates of deuteration and olefin-exchange and values of the coefficient of spread* (*S*) *of ethanes formed.*

Catalyst	Temp.	Deuteration (R_1) (%/min./10 mg.)	Exchange (R_2) (D atoms/100 mol./min./10 mg.)	R_2/R_1	*S*
Fe	−100°	1·54	3·60	2·34	5·68
Ni	−100	2·30	5·25	2·28	5·34
Rh	−104	18·0	18·3	1·02	3·88
W	− 99	3·42	0·26	0·08	0·53

at −100° on nickel gave rise to a small percentage of ethane, in agreement with the findings of Jenkins and Rideal [10] on the decomposition of ethylene in the absence of hydrogen.

As particular interest was associated with the initial distributions of products, these were determined from the graphs together with the aid of the rates given in Table 3; the values found, expressed as percentages of total initial products, and two theoretical sets to be discussed in the next section, are listed in Table 4.

TABLE 4. *Experimental initial distributions of products and two theoretical sets of values (T_1 and T_2).*

		T_1	Ni	Fe	Rh	W	T_2
Ethylenes	$^3H_1$	41·4	46·7	55·5	34·4	7·0	5·3
	$^3H_2$	18·8	13·2	9·4	7·0	—	0·5
	$^3H_3$	6·4	2·7	1·3	1·7	—	—
	$^3H_4$	1·0	0·7	0·2	0·9	—	—
Ethanes	$^3H_0$	2·8	7·8	13·7	8·4	3·1	2·3
	$^3H_1$	9·9	12·5	9·2	14·4	14·7	23·1
	$^3H_2$	11·1	9·5	6·6	15·8	69·8	60·0
	$^3H_3$	5·7	4·0	2·4	7·4	4·5	7·8
	$^3H_4$	2·2	2·0	1·0	5·0	0·7	0·9
	$^3H_5$	0·6	0·8	0·5	3·6	0·2	0·1
	$^3H_6$	0·1	0·2	0·2	1·4	—	—

THEORY OF THE INITIAL DISTRIBUTIONS OF PRODUCTS.

As mentioned already, Keii [5] has given a theory leading to results in semiquantitative agreement with the experimental initial-product distributions of Turkevich and his co-workers.[2] This theory was based on the reaction scheme favoured by Horiuti. The only reactions taken into account in this scheme were those between chemisorbed "hydrogen" atoms, "ethyl" radicals, and "ethylene" molecules. Although this scheme has many merits, the fact that it is not generally accepted by other workers in the field constitutes a possible disadvantage of Keii's theory. A second disadvantage is that this theory leads to a complicated series of equations which can only give exact quantitative results after a number of simplifying assumptions have been made.

It is possible to develop a general theory based on the probabilities of the various changes which adsorbed entities may undergo on the surface without specifying, in the first instance, the mechanism by which these changes take place. The recent investigation [10] of ethylene adsorbed on nickel in the absence of hydrogen has shown that radicals formed by the dissociative adsorption of ethylene are rehydrogenated too slowly to play a substantial part in either olefin-exchange or hydrogenation. Consequently, the only entities which have to be considered are adsorbed ethylene and adsorbed ethyl radicals. The assumptions of the theory are as follows: (*a*) Every adsorbed ethylene molecule must either become an adsorbed ethyl radical or leave the surface. The chances of these two events are independent of isotopic content and are given by $p/(1 + p)$ and $1/(1 + p)$ respectively, p being the ratio of the chances. (*b*) When an ethylene molecule becomes an ethyl radical there is an equal change of the new "hydrogen" atom adding to either end of the ethylene molecule. The chances of obtaining a deuterium or hydrogen atom in this process are $q/(1 + q)$ or $1/(1 + q)$, respectively. (*c*) Every adsorbed ethyl radical must either revert to an adsorbed ethylene molecule or leave the surface as an ethane molecule. The chances of these two events are independent of isotopic content and are given by $r/(1 + r)$ and $1/(1 + r)$, respectively. (*d*) When an ethyl radical reverts to an adsorbed ethylene molecule, it has an equal chance of losing any of the three "hydrogen" atoms in the methyl group. (*e*) When an ethyl radical takes up a "hydrogen" atom to become a gaseous ethane molecule, the chances of obtaining a deuterium or hydrogen atom are $s/(1 + s)$ and $1/(1 + s)$ respectively.

The fractions of the products appearing as the six ethylenes—$CH_2{:}CH_2$, $CH_2{:}CHD$, $CHD{:}CHD$, $CH_2{:}CD_2$, $CHD{:}CD_2$, and $CD_2{:}CD_2$—are given the symbols A_1—A_6. For simplicity, the amounts of the ethanes formed are evaluated in terms of the fraction of

[10] Jenkins and Rideal, *J.*, 1955, 2490.

products appearing in the gas phase as one of twelve different kinds of ethyl radical, it being understood that each is provided with a "hydrogen" atom according to assumption (*e*). The twelve ethyl radicals are $CH_2{\cdot}CH_3$, $CH_2{\cdot}CH_2D$, $CHD{\cdot}CH_3$, $CHD{\cdot}CH_2D$ $CH_2{\cdot}CHD_2$, $CD_2{\cdot}CH_3$, $CH_2{\cdot}CD_3$, $CD_2{\cdot}CHD$, $CHD{\cdot}CHD_2$, $CHD{\cdot}CD_3$, $CD_2{\cdot}CHD_2$, and $CD_2{\cdot}CD_3$ and the fractions of products represented by these are given the symbols B_1—B_{12}. Once the values of B_1—B_{12} have been determined, it is simple to convert them into fractions of product appearing as various deuteroethanes according to assumption (*e*).

By using the one fundamental generating equation [1]

$$Q_m\left(1 + \sum_n \mu_{mn}\right) = a_m(0) + \sum_l \mu_{lm} Q_l \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

it is possible to write down 18 simultaneous equations for the fractions A_1—A_6 and B_1—B_{12}. In equation (4) Q_m represents any of the symbols A or B, μ_{mn} is the ratio of the chance of an entity of the type m becoming an entity of the type n to the chance of m's leaving the surface, Q_l and μ_{lm} have similar meanings, and $a_m(0)$ represents the fraction of the entity present initially. As the construction of the simultaneous equations is simple they are not quoted in full but two examples are given. The equation for A_2 ($CH_2{\cdot}CHD$) is

$$A_2(1 + p) = \tfrac{2}{3}rB_2 + rB_3 + \tfrac{1}{3}rB_4 + \tfrac{2}{3}rB_5 \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and the equation for B_2 ($CHD{\cdot}CH_2D$) is

$$B_4(1 + r) = pqA_2/2(1 + q) + pA_3/(1 + q) \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The 18 simultaneous equations can be solved to give the values of the fractions A and B to the third place of decimals (in times varying between 1 and 3 hr.) by the relaxation method described by Hartree.[11] The results obtained include a value for A_0, the fraction of non-deuterated ethylene in the initial product. Since this cannot be distinguished from the non-deuterated ethylene already present, it is necessary to scale up the remaining 17 fractions and express them as percentages. In working out the sets of values shown in Table 4, it is assumed that the reaction started from adsorbed [$^2H_0$]ethylene, *i.e.*, $a_m(0) = 1$ for A_1 and $a_m(0) = 0$ for all other entities.

The set of values, T_1, which gives reasonable agreement with the observations on nickel, was obtained with the following values of the parameters :

$$p = 3;\ q = 2;\ r = 12;\ s = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and the set, T_2, in reasonable agreement with the results on tungsten, with

$$p = 3;\ q = 5;\ r = 0{\cdot}4;\ s = 5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

It is perhaps worth noting that the theory would predict the formation of [$^2H_2$]ethane alone with

$$p = q = s = \infty \text{ and } r = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Discussion

The results show that the exchange and the deuteration of ethylene are closely related reactions and that the rates of both reactions are quite rapid on films of the four metals studied at −100°. There is, therefore, a marked difference between the exchange of ethylene and the exchange of ethane for which the metals showed widely different activities. This difference in behaviour is good confirmatory evidence that the slow step in the exchange of ethane is the dissociative adsorption of the molecule. The greatest contrast is found on iron films, which are inactive for the exchange of ethane up to 370°. This is probably because further breakdown of the ethane molecule occurs in the same temperature range as dissociative adsorption of ethane on iron films.

[11] Hartree, "Numerical Analysis," Oxford Univ. Press, 1952, p. 167.

It should be noted that no exchange of ethane is possible on any of the metals at the temperatures used in the present work and so the results in Tables 2 and 4 are due solely to the process of deuteration and exchange of ethylene. In this connection, the correlation between the ratio of exchange to deuteration and the coefficient of spread of the resulting ethanes (Table 3) confirms that the production of ethanes having more or less than two deuterium atoms is closely related to the extent of olefin-exchange taking place. This correlation may be limited to metallic films as catalysts because Wilson *et al.*[3] observed no deuteroethylenes over their supported nickel catalyst although there was a wide spread in the distribution of deuterium in the ethanes obtained. Although the activities of the metals differ widely for ethylene-exchange and ethane-exchange, there are similarities between the distribution of products obtained. The large amount of [$^3H_2$]ethane and the small amounts of deuteroethylenes formed on tungsten are in accord with the predominant part played by a simple exchange mechanism in the exchange of ethane; *i.e.*, an ethyl radical on tungsten, whether formed by dissociative adsorption of ethane or by the half-hydrogenation of ethylene has little chance of dissociating to an adsorbed ethylene molecule. The small value of r of 0·4 is a measure of this tendency and is in agreement with the value of 0·2 for a similar parameter in the work on ethane.[1] The distributions of products on the other three metals are rather similar and differ substantially from a random distribution of two deuterium atoms per ethane molecule.

The agreement between the observed values of the mean deuterium number of the ethanes in Table 2 and the values to be expected after taking into account the small amount of HD produced lends support to the reliability of the analyses. The only value of M substantially greater than 2 in that Table was that for the ethanes formed on nickel wire [2] at the high temperature of 90° where the production of HD was sufficiently rapid to allow a substantial increase in the amount of deuterium in the ethanes.

The most reliable evidence for pressure-dependence in the present work is the linear rate of production of total ethanes implying a zero order with respect to ethylene for the deuteration reaction. However, the similarity of the final distributions of products obtained with different gas mixtures over nickel is some confirmation that the kinetics of exchange and deuteration are identical.

Allowance being made for the different surface areas of the films,[8] the rates of deuteration in Table 3 can be converted into relative rates with respect to equal areas of catalyst, that for rhodium being taken as unity. These are shown in Table 5 together with Beeck's results for hydrogenation at 0°. The spread of values is much less at −100° and the value

TABLE 5. *Comparative rates of hydrogenation at 0° and deuteration at −100°.*

Catalyst	Rh	Ni	Fe	W
Hydrogenation at 0°	1	$1·7 \times 10^{-3}$	9×10^{-4}	10^{-4}
Deuteration at −100°	1	$1·1 \times 10^{-1}$	4×10^{-3}	5×10^{-3}

for tungsten has moved up to a position intermediate between those for nickel and iron. This change of position for tungsten was not only to be expected since Beeck gave the activation energy as 2·4 kcal./mole for tungsten compared with 10·7 kcal./mole for the other metals, but also improves the correlation between catalytic activity and the product of valency times percentage of *d*-character of the intermetallic bonds first noted by Schuit [12] for this reaction.

The mechanism of the exchange and hydrogenation or deuteration of ethylene is still a subject of some controversy and it is possible that a number of the different mechanisms that have been put forward all play a part. It was considered of importance to put forward the general theory (p. 740) not based on any particular mechanism but which, when more information is available, may indicate the extent to which different mechanisms contribute to the overall reaction. Jenkins and Rideal [10] have established that, in the absence of hydrogen, ethylene gives rise to some 80% coverage of a nickel surface by acetylenic complexes, and that half the remaining surface can be covered by chemisorbed hydrogen

[12] Schuit, *Discuss. Faraday Soc.*, 1950, **8**, 205.

atoms in pairs. They have suggested [13] a mechanism for hydrogenation and exchange on the assumption that the whole reaction takes place on the isolated pairs of sites left after the formation of acetylenic complexes. This mechanism alone is not sufficient to account for the initial product of [$^2H_3$]- and [$^2H_4$]-ethylene observed in the present work. The presence of added hydrogen must cause a reduction in the number of acetylenic complexes and must favour the existence of the more highly hydrogenated entities such as ethylene molecules and ethyl radicals. The fact that Jenkins and Rideal [10] found no evidence for chemisorbed ethylene in the absence of added hydrogen does not preclude its existence during hydrogenation. Confirmation of, at least, the transitory existence of chemisorbed ethylene follows from the fact that some of the acetylenic complexes can be converted into ethane by adding hydrogen. However, the existence of chemisorbed hydrogen, established by Jenkins and Rideal, together with the fact that hydrogen–deuterium exchange and the ortho–para-hydrogen conversion are almost completely inhibited [14] in the presence of ethylene, comprise good evidence that neither of these reactions can take place through a complex of three " hydrogen " atoms on a single site as proposed by Couper and Eley.[15]

The mechanism put forward by Horiuti [6] makes no allowance for the Rideal type of reaction involving a gaseous molecule reacting with a chemisorbed entity which Twigg [14] claimed was necessary to explain the observed kinetics. Wilson *et al.*[3] have suggested that exchange of the olefin was achieved by the direct transfer of " hydrogen " atoms between adsorbed olefin and adsorbed alkyl radicals. They argued that, if there were appreciable quantities of hydrogen atoms on the surface, the return of hydrogen to the gas phase would be possible by the mechanism proposed by Couper and Eley, and consequently that reactions involving chemisorbed hydrogen were unimportant. This conclusion may not be valid in light of the new evidence. Wilson and his co-workers also suggested that the chance of obtaining a deuterium atom was the same when an adsorbed alkyl radical was converted into a gaseous alkane as when an adsorbed alkene was converted into an adsorbed alkyl radical; this hypothesis was introduced to account for the agreement between the observed quantities of [$^2H_0$]- and [$^2H_1$]-butane and the calculated values for a random distribution of 2·13 deuterium atoms per molecule. However, a simple calculation shows that different probabilities of obtaining a deuterium atom in the two steps can still lead to the same values for [$^2H_0$]- and [$^2H_1$]-butane provided the two probabilities continued to give a resultant chance of 2·13 deuterium atoms per molecule. For this reason, two different probabilities for these steps are included in the general theory given in this paper.

The agreement between the observed initial product distributions on nickel and tungsten and the values calculated from the general theory is very satisfactory. It is not possible at this stage to specify the part played by different mechanisms but the parameters p, q, r, and s are certainly fundamental quantities for the overall reaction, and when more information is available about the effect of gas pressures and temperature on these parameters the contributions of different mechanisms may become apparent. An interesting feature of the general theory is that it predicts not only the proportions of the different deuteroethanes but also the position of the deuterium atoms in these compounds, *i.e.*, the extent to which [$^2H_2$]ethane is composed of $CH_3{\cdot}CHD_2$ and $CH_2D{\cdot}CH_2D$. Consequently, when mass-spectrometric technique is sufficiently improved to permit the determination of all these isomers, some most illuminating results may come to light.

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[13] Jenkins and Rideal, *J.*, 1955, 2496.
[14] Twigg, *Discuss. Faraday Soc.*, 1950, **8**, 152.
[15] Couper and Eley, *ibid.*, p. 172.

147. *Thermodynamics of Ion Association. Part II.* Alkaline-earth Acetates and Formates.*

By G. H. Nancollas.

Thermodynamic equilibrium constants for the association, in aqueous solution, of magnesium, calcium, strontium, and barium ions with acetate and formate ions have been obtained from potentiometric measurements at 25° and 35°. ΔG, ΔH, and ΔS for the reaction $M^{2+} + A^- \rightleftharpoons MA^+$ have been calculated, and the anomalous complex-forming behaviour of the magnesium ion is interpreted in terms of a hydration effect. Calculated hydration entropies of the ion pairs are compared with values obtained from empirical relations.

Ions of the alkaline-earth series in their association with inorganic and organic anions have especially interesting properties. The absence of reliable heat and entropy data has restricted discussion to a consideration of the association constants at one temperature and, if it is assumed that the complexes are formed as a result of electrostatic interactions between the oppositely charged ions, the order of stability of the complexes for a given ligand should be in the inverse order of the radii of the cations, *i.e.*, $Mg^{2+} > Ca^{2+} > Sr^{2+} > Ba^{2+}$. Colman-Porter and Monk [1] have shown that the stabilities of a number of organic salts of calcium, strontium, and barium fall in this sequence. The position of magnesium, however, which is the most hydrated alkaline-earth cation, is by no means certain. Williams,[2] in a survey covering both inorganic and organic salts of the alkaline-earths, has shown that the stability constants of organic acid complexes of magnesium are very often smaller than those of the calcium complexes.

In a previous paper,[3] it was shown that the entropy of association of a single cation with different anions depends largely on the entropy of hydration of the anion. The present work is a continuation of a proposed systematic study of the thermodynamic properties of ion association in aqueous solution and deals with systems in which the cation is varied. The derived thermodynamic data provide information concerning the behaviour of the hydrated magnesium ion as a complexing reagent.

Experimental

"AnalaR" acids and alkaline-earth chlorides were used without further purification: stock solutions were analysed volumetrically (±0·1%) for acid by alkalimetry using carbon dioxide-free sodium hydroxide, and for chloride by the Mohr titration.[4] Conductivity water, prepared by mixed-bed deionisation,[5] and Grade A glassware were used throughout.

pH measurements were made with a glass electrode incorporated in the complete cell:

Ag/AgCl, HCl(0·2M)|glass|Solution under study|sat. KCl|Calomel electrode

The liquid junction was formed in a special apparatus which has been described elsewhere.[6] The glass electrodes were made from Corning 015 glass and had resistances of 10—20 megohms. Potentials were measured on a Tinsley potentiometer reading to 0·1mv, with a valve voltmeter as null-point indicator. The cell was contained in an oil-bath (thermostat), and reproducibility was greatly improved by maintaining the cell at its working temperature for at least 12 hr. before use. The electrode system was standardised before and after each set of measurements, with the buffer solutions: 0·05M-potassium hydrogen phthalate,[7] pH 4·005 at 25° and 4·021 at 35°; B.D.H. tabloid phosphate buffer, pH 6·99 at 25° and 6·97 at 35°. The procedure consisted in determining the pH of solutions containing known amounts of the monocarboxylic acid, sodium

* Part I, *J.*, 1955, 1458.

[1] Colman-Porter and Monk, *J.*, 1952, 4363.
[2] Williams, *J.*, 1952, 3770.
[3] Nancollas, *J.*, 1955, 1458.
[4] Vogel, "Quantitative Inorganic Analysis," Longmans, 1947, p. 311.
[5] Davies and Nancollas, *Chem. and Ind.*, 1950, **7**, 129.
[6] Dunsmore and Speakman, *Trans. Faraday Soc.*, 1954, **50**, 236.
[7] Brit. Stand., 1647, 1950.

hydroxide, and metal chloride; these solutions were prepared immediately before use, and E.M.F. readings were reproducible to within ±0·1 mv.

Results.—The pH being defined by $-\log f_1[H^+]$, where f_1 is the mean activity coefficient for univalent ions, standardisation of the electrode system was checked by measurements with acetic acid–sodium acetate buffer solutions at 25° and 35°. The calculated thermodynamic acid dissociation constants, K_a, were within ±1% of the values, $1{\cdot}754 \times 10^{-5}$ at 25° and $1{\cdot}728 \times 10^{-5}$ at 35°, which were obtained by Harned and Ehlers.[8] For formic acid,[9] $K_a = 1{\cdot}772 \times 10^{-4}$ at 25° and $1{\cdot}747 \times 10^{-4}$ at 35°.

The pH of acetate and formate buffer solutions in the presence of the bivalent metal chlorides, which are known to be highly dissociated, can be satisfactorily interpreted in terms of the formation of only one complex, MA^+. The concentrations of the ionic species present in solution were obtained from the equations: (*a*) for the total concentration of bivalent metal, $T_m = [M^{2+}] + [MA^+]$; (*b*) for the total acid concentration, $T_a = [HA] + [A^-] + [MA^+]$; (*c*) for electroneutrality, $[Na^+] + [H^+] = [MA^+] + [A^-]$; and (*d*) for the dissociation constant of the acid, $K_a = [H^+][A^-]f_1^2/[HA]$.

Thermodynamic association constants, K, were obtained by successive approximations of I, the ionic strength, from the equation

$$\log K = \log [MA^+]/[M^{2+}][A^-] + 2[I^{\frac{1}{2}}/(1 + I^{\frac{1}{2}}) - 0{\cdot}2I],$$

where $I = 3T_m + 2[A^-] - [Na^+] - [H^+]$.

K values are given in Table 1, together with the concentrations of ionic species in millimoles/l.

TABLE 1. pH *Determinations* (*concns. in mmoles/l.*).

T_a	T_m	NaOH	pH	HA	A^-	MA^+	M^{2+}	I	K
				Magnesium acetate at 25°					
20·14	9·99	10·76	4·705	9·36	10·00	0·78	9·14	39·1	17·6
20·14	9·99	9·04	4·559	11·07	8·40	0·67	9·25	37·5	17·5
20·14	6·95	9·98	4·655	10·13	9·45	0·56	6·39	29·7	17·6
20·14	4·96	9·98	4·668	10·13	9·59	0·41	4·55	24·0	17·0
20·14	3·97	11·34	4·791	8·78	10·96	0·40	3·57	22·2	18·0
4·02	9·92	2·04	4·672	1·96	1·90	0·165	9·76	31·8	17·3
4·03	9·92	1·361	4·375	2·62	1·290	0·116	9·80	31·2	17·8
4·03	9·92	1·134	4·277	2·81	1·098	0·096	9·82	30·9	17·5
4·03	9·92	0·907	4·160	3·03	0·906	0·083	9·84	30·8	18·0
4·03	9·92	0·680	4·035	3·24	0·725	0·062	9·86	30·4	17·5
								Mean	17·6
				Magnesium acetate at 35°					
20·08	9·89	12·88	4·907	7·19	12·02	0·87	9·02	40·8	16·6
20·08	9·89	11·81	4·811	8·25	11·05	0·78	9·11	40·1	16·1
20·08	9·89	10·73	4·715	9·33	10·00	0·75	9·14	39·3	16·9
20·08	9·89	9·01	4·568	11·04	8·44	0·60	9·29	37·5	15·6
10·04	6·93	7·52	5·147	2·51	7·14	0·39	6·54	27·8	15·9
10·04	6·93	6·02	4·851	4·00	5·71	0·33	6·60	26·1	16·2
								Mean	16·2
				Calcium acetate at 25°					
20·14	9·98	10·76	4·705	9·36	10·00	0·78	9·20	39·1	17·5
20·14	9·98	10·21	4·659	9·91	9·49	0·74	9·24	38·7	17·2
20·14	9·98	9·04	4·559	11·07	8·40	0·67	9·31	37·7	17·5
20·14	6·99	11·34	4·771	8·78	10·76	0·60	6·39	31·1	17·0
20·14	4·99	12·47	4·883	7·66	11·98	0·50	4·49	26·5	17·3
20·14	3·99	13·61	4·998	6·52	13·20	0·42	3·57	24·8	16·4
10·07	4·99	8·39	5·376	1·67	8·02	0·37	4·62	23·6	18·4
								Mean	17·5
				Calcium acetate at 35°					
20·08	9·95	12·88	4·905	7·19	11·95	0·93	9·02	40·8	18·4
20·08	9·95	11·81	4·806	8·25	10·96	0·87	9·08	39·9	18·3
20·08	9·95	10·73	4·712	9·33	9·95	0·80	9·15	39·3	18·3
20·08	9·95	9·01	4·564	11·04	8·35	0·70	9·25	37·5	18·6
10·04	6·97	7·52	5·147	2·51	7·10	0·43	6·54	27·7	17·7
10·04	6·97	6·02	4·847	4·00	5·66	0·38	6·59	26·0	18·8
								Mean	18·4

[8] Harned and Ehlers, *J. Amer. Chem. Soc.*, 1933, **55**, 652.
[9] Harned and Embree, *ibid.*, 1934, **56**, 1042.

TABLE 1. (*Continued.*)

T_s	T_m	NaOH	pH	HA	A^-	MA^+	M^{2+}	I	K
				Strontium acetate at 25°					
20·14	9·99	15·06	5·121	5·07	14·19	0·88	9·11	43·3	14·5
20·14	9·99	11·84	4·806	8·28	11·15	0·71	9·28	40·5	14·3
20·14	9·99	10·76	4·711	9·36	10·10	0·68	9·31	39·2	14·9
20·14	9·99	9·04	4·563	11·07	8·49	0·58	9·41	37·9	14·8
10·07	6·99	7·96	5·245	2·10	7·59	0·38	6·61	28·3	14·5
10·07	6·99	6·03	4·845	4·02	5·76	0·29	6·70	26·4	13·9
								Mean	14·5
				Strontium acetate at 35°					
20·08	9·96	12·88	4·909	7·19	12·09	0·80	9·16	41·2	15·1
20·08	9·96	11·81	4·814	8·25	11·11	0·72	9·24	40·3	14·6
20·08	9·96	10·73	4·716	9·33	10·05	0·70	9·26	39·2	15·6
20·08	9·96	9·01	4·571	11·04	8·47	0·57	9·39	37·9	14·7
10·04	6·97	7·52	5·150	2·51	7·16	0·37	6·60	28·0	15·0
10·04	6·97	6·02	4·850	4·00	5·72	0·32	6·65	26·3	15·5
								Mean	15·1
				Barium acetate at 25°					
20·14	9·99	10·76	4·710	9·36	10·12	0·66	9·33	39·4	14·5
20·14	9·99	10·21	4·662	9·91	9·59	0·64	9·35	38·8	14·7
20·14	9·99	9·04	4·564	11·07	8·51	0·56	9·43	37·9	14·2
20·14	6·99	11·34	4·776	8·78	10·85	0·51	6·48	31·3	14·1
20·14	4·99	12·47	4·886	7·65	12·06	0·43	4·56	26·7	14·5
20·14	3·99	13·61	4·999	6·52	13·24	0·38	3·61	24·8	14·5
10·07	4·99	8·39	5·379	1·67	8·11	0·29	4·70	22·8	13·5
10·07	4·99	6·12	4·872	3·93	5·91	0·23	4·76	20·6	14·2
								Mean	14·2
				Barium acetate at 35°					
20·08	9·96	12·88	4·914	7·19	12·21	0·68	9·28	41·4	12·7
20·08	9·96	11·81	4·816	8·25	11·20	0·63	9·33	40·4	12·7
20·08	9·96	10·73	4·721	9·33	10·19	0·56	9·40	39·5	12·5
20·08	9·96	9·01	4·574	11·04	8·53	0·51	9·45	37·9	13·0
10·04	6·97	7·62	5·176	2·41	7·31	0·32	6·65	27·9	12·5
10·04	6·97	6·02	4·857	4·00	5·80	0·24	6·75	26·4	12·0
								Mean	12·5
				Magnesium formate at 25°					
19·64	9·92	10·76	3·729	8·66	9·85	1·13	8·79	38·5	26·9
19·67	9·92	9·07	3·585	10·30	8·39	0·98	8·94	37·2	26·3
19·64	9·92	9·04	3·583	10·29	8·34	1·01	8·91	37·1	27·7
19·67	6·95	9·75	3·660	9·66	9·20	0·81	6·14	29·3	27·1
19·67	3·97	11·34	4·027	5·95	13·06	0·66	3·31	24·3	27·8
9·84	4·96	8·39	4·439	1·41	7·90	0·53	4·43	22·3	27·0
9·84	4·96	6·12	3·906	3·58	5·86	0·40	4·56	20·3	26·2
								Mean	27·0
				Magnesium formate at 35°					
19·59	9·89	12·88	3·934	6·57	11·82	1·20	8·69	40·3	24·3
19·59	9·89	11·81	3·834	7·60	10·87	1·12	8·77	39·4	24·3
19·59	9·89	10·73	3·740	8·64	9·87	1·08	8·81	38·6	25·4
19·59	9·89	9·01	3·595	10·28	8·40	0·91	8·98	37·2	24·1
9·79	6·93	7·52	4·191	2·20	7·00	0·59	6·34	27·2	25·2
9·79	6·93	6·02	3·886	3·62	5·69	0·48	6·45	26·0	24·1
								Mean	24·5
				Calcium formate at 25°					
19·64	9·98	10·76	3·729	8·66	9·85	1·13	8·85	38·7	26·7
19·67	9·98	10·21	3·682	9·22	9·38	1·07	8·91	38·2	26·1
19·64	9·98	9·04	3·583	10·29	8·34	1·01	8·97	37·3	27·5
19·67	6·99	11·34	3·788	8·14	10·62	0·91	6·07	34·1	27·8
19·67	4·99	12·47	3·912	7·05	11·90	0·72	4·27	26·2	26·3
19·67	3·99	13·61	4·027	5·95	13·08	0·64	3·35	24·4	26·5
9·84	4·99	8·39	4·439	1·41	7·90	0·53	4·46	22·3	27·2
9·84	4·99	6·12	3·905	3·58	5·85	0·41	4·58	20·4	26·8
								Mean	27·0
				Calcium formate at 35°					
19·59	9·95	12·88	3·929	6·57	11·67	1·35	8·60	40·2	28·1
19·59	9·95	11·81	3·831	7·60	10·70	1·29	8·66	39·3	28·8
19·59	9·95	10·73	3·735	8·64	9·79	1·16	8·80	38·6	27·2
19·59	9·95	9·01	3·588	10·27	8·29	1·03	8·92	37·2	28·4
9·79	6·97	7·62	4·215	2·10	7·04	0·65	6·32	26·9	28·0
9·79	6·97	6·12	3·900	3·52	5·69	0·58	6·39	25·9	28·9
								Mean	28·5

TABLE 1. (*Continued.*)

T_s	T_m	NaOH	pH	HA	A^-	MA^+	M^{2+}	I	K
				Strontium formate at 25°					
19·64	9·99	15·06	4·155	4·50	13·75	1·39	8·60	42·3	24·9
19·64	9·99	11·84	3·827	7·62	10·90	1·12	8·87	39·8	24·1
19·64	9·99	10·76	3·733	8·66	9·96	1·02	8·97	38·9	24·0
19·64	9·99	9·04	3·587	10·29	8·40	0·95	9·04	37·4	25·4
9·82	6·99	7·96	4·297	1·80	7·40	0·62	6·37	27·9	24·6
9·82	6·99	6·03	3·888	3·64	5·72	0·46	6·53	26·1	23·0
								Mean	24·4
				Strontium formate at 35°					
19·59	9·96	12·88	3·932	6·57	11·78	1·24	8·72	40·5	25·2
19·59	9·96	11·81	3·834	7·60	10·84	1·15	8·81	39·6	25·1
19·59	9·96	10·73	3·739	8·64	9·87	1·08	8·88	38·7	25·3
19·59	9·96	9·01	3·594	10·28	8·40	0·91	9·05	37·4	24·4
9·79	6·97	7·52	4·190	2·20	6·98	0·61	6·36	27·3	26·0
9·79	6·97	6·02	3·885	3·62	5·67	0·50	6·46	26·0	25·2
								Mean	25·2
				Barium formate at 25°					
19·64	9·99	10·76	3·732	8·66	9·95	1·03	8·96	38·9	23·7
19·67	9·99	10·21	3·684	9·22	9·42	1·03	8·96	38·4	24·9
19·64	9·99	9·04	3·587	10·29	8·40	0·95	9·04	37·4	25·4
19·67	6·99	11·34	3·799	8·14	10·70	0·83	6·16	30·8	24·2
19·67	4·99	12·47	3·913	7·06	11·91	0·70	4·29	26·2	25·0
19·67	3·99	13·61	4·031	5·95	13·14	0·58	3·41	24·5	23·6
9·84	4·99	8·39	4·440	1·41	7·94	0·49	4·50	22·4	24·1
9·84	4·99	6·12	3·908	3·58	5·90	0·36	4·63	20·5	23·0
								Mean	24·2
				Barium formate at 35°					
19·59	9·96	12·88	3·938	6·57	11·93	1·09	8·87	40·7	21·5
19·59	9·96	11·81	3·839	7·60	10·97	1·02	8·94	39·8	21·5
19·59	9·96	10·73	3·742	8·64	9·95	1·00	8·96	38·8	22·9
19·59	9·96	9·01	3·599	10·28	8·53	0·78	9·18	37·6	21·0
9·79	6·97	7·52	4·198	2·20	7·07	0·52	6·45	27·4	22·0
9·79	6·97	6·02	3·889	3·62	5·73	0·44	6·53	26·2	22·0
								Mean	21·8

There are comparatively few published data with which comparisons can be made. Cannan and Kibrick [10] obtained from potentiometric measurements, apparent dissociation constants for alkaline-earth acetates at an ionic strength of 0·2. Applying an approximate correction for this, we have the K values, Mg^{2+} 14, Ca^{2+} 14, Sr^{2+} 12, and Ba^{2+} 10. Colman-Porter and Monk [1] cite figures, obtained from solubilities of some alkaline-earth iodates, which are substantially lower, varying from 6·3 and 5·9 respectively for the formate and acetate of calcium, to 4·0 and 2·6 for those of barium. The reason for this is not clear, although, since the solubility method involves a consideration of numerous ion pairs and the solubility of some of the iodates is extremely small, the present results are probably more accurate. Dunsmore and Speakman [6] in a determination of dissociation constants by four different methods conclude that when pH measurements can be carried out rigorously, very reliable results can be expected.

DISCUSSION

The process of complex formation may be described in two stages, the first corresponding to the formation of an ion pair, $M^{2+}(H_2O)_nA^-$, and the second to the formation of a more covalent complex, $MA^+(H_2O)_{n-1}$. The latter, of course, is usually simply written MA^+. A given ligand, for example, may not be able to displace the water of hydration from the smaller magnesium ion as easily as from the larger cations. This is reflected in the abnormally low stability of magnesium complexes (Table 1); there is a small variation in K at 25°, more marked at 35°, in the sequence $Mg^{2+} \ll Ca^{2+} > Sr^{2+} > Ba^{2+}$.

ΔG, ΔH, and ΔS values, calculated from the experimental K values at 25° and 35°, are given in Table 2. The linear relation between ΔS(association) and ΔS(hydration) of the cation is shown in Fig. 1. This was predicted in Part I [3] in which a similar relation was

[10] Cannan and Kibrick, *J. Amer. Chem. Soc.*, 1938, **60**, 2314.

TABLE 2. *Thermodynamic properties.*

Reaction	ΔG at 25° (kcal. mole^{-1})	ΔH (kcal. mole^{-1})	ΔS (cal. deg.$^{-1}$ mole^{-1})	$S_{trans}(MA^+)$ (cal. deg.$^{-1}$ mole^{-1})	$S_{rot}(MA^+)$ (cal. deg.$^{-1}$ mole^{-1})	ΔS_g (cal. deg.$^{-1}$ mole^{-1})
$Mg^{2+},H{\cdot}CO_2^-$ ...	−1·94	−1·77	0·6	38·8	24·6	−30·1
$Ca^{2+},H{\cdot}CO_2^-$	−1·94	0·98	10	39·4	25·6	−30·0
$Sr^{2+},H{\cdot}CO_2^-$	−1·88	0·59	8·3	40·7	26·5	−30·3
$Ba^{2+},H{\cdot}CO_2^-$ ...	−1·87	−1·89	−0·3	41·7	27·1	−30·0
$Mg^{2+},CH_3{\cdot}CO_2^-$ ...	−1·69	−1·52	0·6	37·5	27·7	−32·0
$Ca^{2+},CH_3{\cdot}CO_2^-$ ...	−1·69	0·91	8·7	37·9	28·6	−32·2
$Sr^{2+},CH_3{\cdot}CO_2^-$ ...	−1·58	0·74	7·8	39·0	29·4	−32·8
$Ba^{2+},CH_3{\cdot}CO_2^-$ ...	−1·57	−2·32	−2·5	39·8	30·0	−32·7

observed between the entropy of association of lead ions with halide ions, and ΔS(hydration) of the anions. An even more extensive linear correlation has been suggested by Williams.[11] If the hydration shell of the Mg^{2+} ion is preserved in its association reactions, then, for comparison with the other systems, the experimental ΔS(association) will be too low by

FIG. 1. *Relation between the entropy of association and the entropy of hydration of the cation:* 1, *acetates* (○); 2, *formates* (+).

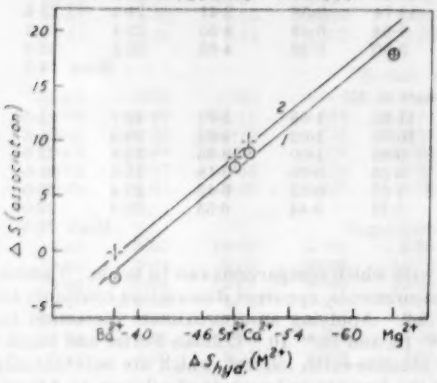
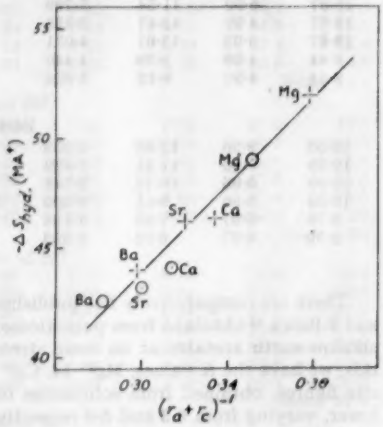


FIG. 2. *Plot of* $\Delta S_{hyd}(MA^+)$ *against* $(r_a + r_c)^{-1}$: ○, *acetates*; +, *formates*



16·7 cal. deg.$^{-1}$ mole^{-1}, the entropy of an aqueous water molecule. Fig. 1 shows that the corrected figures are approximately consistent with the same straight lines.

The entropy of the association reaction $M^{2+} + A^- \rightleftharpoons MA^+$ in aqueous solution may be written:[3]

$$\Delta S = \Delta S_g + \Delta S_{hyd}(MA^+) - \Delta S_{hyd}(M^{2+}) - \Delta S_{hyd}(A^-) \quad . \quad . \quad . \quad . \quad (1)$$

where ΔS_g and ΔS_{hyd} represent, respectively, the entropy of association of the ions in the gas phase, and the hydration entropy of the ion concerned.

$\Delta S_{hyd}(M^{2+})$ and $\Delta S_{hyd}(H{\cdot}CO_2^-)$ were obtained from the known standard and gas-phase entropies.[12] $\Delta S_{hyd}(CH_3{\cdot}CO_2^-)$ was estimated (−35 cal. deg.$^{-1}$ mole^{-1}) from the formate value by assuming a linear relation between $\Delta S_{hyd}(A^-)$ and the reciprocal of the ionic radius.

ΔS_g contains both translational and rotational terms and is given by

$$\Delta S_g = S_{trans}(MA^+) - S_{trans}(M^{2+}) - S_{trans}(A^-) - S_{rot}(A^-) + S_{rot}(MA^+) \quad . \quad (2)$$

Translational entropies at 25° were calculated from the Sackur–Tetrode equation, $S_{trans} =$

[11] Williams, Proc. Symp. Co-ord. Chem., Copenhagen, 1953, 68.
[12] Latimer, "Oxidation Potentials," Prentice-Hall, New York, 1952.

$1{\cdot}5R \ln M + 26{\cdot}03$, where M = molecular weight. The rotational entropies of acetate and formate ions were obtained from the equation: [13]

$$S_{rot} = 2{\cdot}287\ (3 \log T + \log I_A I_B I_C) - 5{\cdot}384 \quad . \quad . \quad . \quad . \quad (3)$$

the products of the moments of inertia, $I_A I_B I_C$, being calculated by the method described previously: [3] at 25°, $S_{rot}(H{\cdot}CO_2^-) = 20{\cdot}6$, $S_{rot}(CH_3{\cdot}CO_2^-) = 23{\cdot}4$ cal. deg.$^{-1}$ mole^{-1}.

By using, for gas-phase calculations, the dimensions of solid barium formate derived from *X*-ray data by Sugawara *et al.*,[14] and assuming that the formate and the acetate complexes are similarly planar with centres of mass lying on the H–C $\cdots$ M and CH_3–C $\cdots$ M axes respectively, $S_{rot}(MA^+)$ values have been obtained from equation 3. These are given in Table 2 together with the entropies (ΔS_g) of association of the gaseous ions.

Substitution of these calculated entropies in equation 1 permits the evaluation of $\Delta S_{hyd}(MA^+)$. Fig. 2 shows the good linearity of a plot of $\Delta S_{hyd}(MA^+)$ against $(r_c + r_a)^{-1}$, where r_c and r_a are the radii of the cations and anions respectively. The latter are "pseudo-spherical" radii and were obtained from the calculated total volumes of the anions: for formate, $r_a = 2{\cdot}0$; for acetate, $r_a = 2{\cdot}2$. They may be compared with the values, 1·7 and 2·2 respectively, calculated from aqueous ionic mobilities by means of Stokes's law.

Cobble [15] has defined a corrected entropy $\bar{S}'$ of a complex ion by the equation: $\bar{S}' = \bar{S}^0 - nS^0(H_2O)$ where $\bar{S}^0$ is the partial molal entropy and n represents the number of water molecules replaced from the normal aquated ion by the complex-forming agent. When this corrected entropy and empirical relations suggested by Cobble are used, the entropy of hydration may be written:

$$\Delta S_{hyd}(MA^+) = 49 - 99z\mathrm{F}/(r_a + r_c) + nS^0(H_2O) - S_g(MA^+) \quad . \quad . \quad (4)$$

where z is the charge. The value of F, a structural factor depending upon the geometry of the ion, which best fits the data is 1·44. On the assumption that $n = 0$ for magnesium complexes which retain the hydration shell of the cation, and $n = 1$ for the other complexes, the calculated $\Delta S_{hyd}(MA^+)$ values are given in Table 3. The excellent agreement with the

TABLE 3.

	Acetates				Formates			
	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
$-\Delta S_{hyd}(MA^+)$ (expt.)	66·1	44·3	43·3	42·6	69·1	46·3	46·4	44·2
$-\Delta S_{hyd}(MA^+)$ (calc.)	66	45	44	43	68	47	46	45

experimental values illustrates the success of these empirical methods of correlation. The accumulation of experimental thermodynamic results would thus be generally useful in predicting the properties of as yet undetermined species.

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[13] Herzberg, "Infra-red and Raman Spectra," Van Nostrand, New York, 1945, Chap. 5
[14] Sugawara, Kakudo, Saito, and Nitta, *X-Sen.*, 1951, **6**, 85.
[15] Cobble, *J. Chem. Phys.*, 1953, **21**, 1443, 1446.

148. *The S_N Mechanism in Aromatic Compounds. Part XVI.**

By Brian A. Bolto, Mark Liveris, and Joseph Miller.

The very powerful activation by two types of cationic groups for aromatic S_N reactions has been compared with that of the dipolar nitro-group. The importance of the conjugative (T) effect is shown by the order of activating power, $N_2^+ \gg \overset{+}{N}O_2^- \gg NMe_3^+$, the N_2^+ being the most activating group recorded in these reactions.

The influence of the first insertion of an activating group into a halogenobenzene is shown to be considerably greater than subsequent insertion of the same group, both rate constants and activation energy being considered.

In the course of this work the replacement of fluorine in fluorobenzene has been measured, and also the effect of varying ionic strength on the reactions between an anion and a cation in both methanol and water.

In the classification of substituents in aromatic S_N reactions by one of us,[1] class (i) refers to groups with a positive pole attached to the ring. It was subdivided into classes (i) (*a*) and (*b*) according to whether the substituent could exhibit only $-I$ or $-I,-T$ effect. For the resultant effect at *ortho*- and *para*-positions the latter subclass was predicted to have the greater activating power. Some preliminary results have been published.[2] The general discussion and predictions are now confirmed, the trimethylammonium and the diazonium group being used as representatives of classes (i) (*a*) and (*b*).

Table 1 records the rate constants, and Table 2 the derived quantities for the replace-

TABLE 1.*

Rate constant, $10^5 k_2$ (l. mole^{-1} sec.$^{-1}$)

Compound	(*a*) at temperatures shown in parentheses					(*b*) calc. at: 0°	50°	100°
(i) †	4·01 (193·5°)	8·08 (202·5°)	15·1 (210·5°)	—	—	$0{\cdot}0_{10}101$	$0{\cdot}0_4216$	$0{\cdot}0_3318$
(ii)	77·7 [88·8] (−4·8°)	150 [170] (0°)	318 [364] (4·9°)	319 [365] (5·2°)	—	[170] {170,000}	— —	— —
(iii)	58·7 (35·55°)	104 (40·2°)	188 (47·3°)	218 (48·05°)	5210 (82·0°)	0·626	264	22,000
(iv)	6·23 (81·8°)	36·9 (100·1°)	123 (113·7°)	456 (130·2°)	—	$0{\cdot}0_3137$	0·185	36·0
(v) (*a*) ‡	47·6 [151] (25·0°)	152 [505] (35·2°)	439 [1540] 44·95°)	454 [1590] (45·5°)	—	— [5·28]	— [2650]	— [251,000]
(*b*)	11·9 [13·8] (59·4°)	123 [142] (82·4°)	187 [217] (86·8°)	—	—	— [$0{\cdot}0_2529$]	— [4·83]	— [708]
(vi)	138 (0°)	710 (15·0°)	1180 (20·0°)	1950 (25·0°)	—	138	17,900	632,000

* Values in brackets are corrected to zero ionic strength. Values in braces are corrected to zero ionic strength, and estimated for OMe^- in MeOH by using the corrected relationship of (v) (*a*) and (*b*). Values of k_2 are accurate to ± 2%.

† Bevan and Bye (*J.*, 1954, 3091) have reported values for fluorobenzene at two temperatures which they regard as subject to some doubt.

‡ A similar result for the 4-chloro-compound (not corrected for ionic-strength effects) has been reported by Bunnett *et al.* (*J. Amer. Chem. Soc.*, 1953, **75**, 642).

ment of the halogen atom in (i) fluorobenzene, (ii) *p*-fluorobenzenediazonium borofluoride, (iii) *p*-fluoronitrobenzene, (iv) *o*-bromonitrobenzene, (v) (*a*) and (*b*) 4-bromo-*NNN*-trimethyl-3-nitroanilinium chloride, (vi) 1-bromo-2 : 4-dinitrobenzene. Replacement is by methoxyl group in methanol except for (ii) and (v) (*b*) which are by hydroxyl group in water. In the

* Part XV, *J.*, 1955, 2929.

[1] Miller, *Rev. Pure Appl. Chem.* (*Australia*), 1951, **1**, 171.
[2] Bolto and Miller, *Chem. and Ind.*, 1953, 640.

TABLE 2 (see footnote to Table 1.)

Substituent		Substituent rate factor at 0°	Substituent rate factor at 50°	Substituent rate factor at 100°	Activation energy (E) (cal.)	Frequency factor ($\log_{10} B$)
H		1	1	1	34,900	12·0
p-N_2^+		{1·68 × 10^{16}}	—	—	[21,300]	[14·3]
					{19,1$_{80}$}	{15·6}
p-NO_2		6·20 × 10^{10}	1·33 × 10^9	6·92 × 10^7	21,200	11·7$_5$
H		1	1	1	25,2$_{80}$	11·3$_5$
p-NMe_3^+	(*a*)	[3·85 × 10^4]	[1·43 × 10^4]	[6·97 × 10^3]	[21,7$_{80}$]	[13·1$_6$]
	(*b*)	—	—	—	[23,900]	[11·8$_6$]
p-NO_2		1·14 × 10^6	1·01 × 10^5	1·72 × 10^4	17,100	10·8

manner discussed in the Experimental section, corrections to zero ionic strength are made for (ii), (v) (*a*) and (*b*), and the comparison of (v) (*a*) and (*b*) used to estimate rates and Arrhenius parameters for reaction of (ii) with methoxyl group in methanol.

Discussion of Results.—It is now generally accepted, particularly from the work of Roberts *et al.*,[3] that replacement of halogen in halogenobenzenes by the amino-group takes place by a mechanism involving rearrangement, and thus different from that in the simpler aromatic S_N reactions. The reaction with methoxyl group, however, may well proceed by simple nucleophilic displacement, and it is noteworthy that *p*-difluorobenzene reacts with sodium hydroxide to form *p*-fluorophenol, and that Heppolette and Miller [4] have shown, admittedly for an activated displacement, that the substituent rate factor of fluorine is approximately 1. If then the methanolysis of fluorobenzene is a simple displacement, the substituent rate factors obtained by comparison with it are actual values; if not, then they are *minimum* values, since reaction with rearrangement would necessarily proceed faster than the direct displacement.

The activating order, $N_2^+ \gg NO_2 \gg NMe_3^+$, was obtained by a separate comparison of N_2^+ and NO_2, and NO_2 and NMe_3^+. The first comparison is in the series with no other substituents, while the latter is in one having another powerfully activating substituent also present. Reference to the nitro-group shows that the second series is less sensitive to substituent effects, though the values may be used to make a reasonable estimate from one series to the other. Numerical ratios are: $-I,-T$ cation to $-I,-T$ dipole about 2·7 × 10^5, while the ratio $-I,-T$ dipole to $-I$ cation (less sensitive series) is about 30, and may be estimated as not more than 10^3 if in the more sensitive series. The relative position of nitro-group and trimethylammonium ion is opposite to that in aromatic S_N reactions,[5] illustrating the importance of the electromeric (E) component of the conjugative (T) effect. In comparing the nitro-group with the two cations, the obvious measurement of rate of replacement of halogen in *p*-halogenotrimethylanilinium ion (even with less activating and more easily replaced fluorine) was not attempted owing to expected concurrent and probably faster displacement of trimethylammonium ion,[6] so that following the displacement of the fluoro-group would be impracticable. The change from fluorine to bromine in changing from the more sensitive to the less sensitive series is regarded as unimportant since comparison of the 1-halogeno-2 : 4-dinitrobenzenes [7] with the *o*-halogenonitrobenzenes [8] shows that the activating power of the second nitro-group is very little affected by the nature of the halogen displaced, and thus negligible in comparison with the very marked separation shown here, *viz.*, for substituent rate factors at 0° being 6·20 × 10^{10} for the *p*-nitro-group in the first series, and 1·14 × 10^6 in the second.

The variation of the Arrhenius parameters is in accord with that deduced from the rate constants. Substitution of the diazonium ion into the *para*-position lowers the activation

[3] Roberts, Simmons, Carlsmith, and Vaughan, *J. Amer. Chem. Soc.*, 1953, **75**, 2390.
[4] Heppolette and Miller, *ibid.*, p. 4265.
[5] Ingold, "Structure and Mechanism in Organic Chemistry," G. Bell and Co., 1953, p. 234; Bonner, James, Lowen, and Williams, *Nature*, 1949, **163**, 955.
[6] Cf. Heppolette and Miller, ref. 4; Bolto and Miller, in preparation.
[7] Beckwith, Miller, and Leahy, *J.*, 1952, 3552.
[8] Bolto, Miller, and Williams, *J.*, 1955, 2926.

energy by 13,600 cal. and multiplies the frequency factor by $10^{2\cdot3}$. Allowing that one reaction is with methoxyl in methanol and the other with hydroxyl in water, and using the comparison in this paper for the trimethylanilinium ion, we may estimate the true changes in the parameters as a decrease in activation energy of 15,750 cal. and rise in frequency factor as $\times 10^{3\cdot6}$. The marked lowering of the energy term is characteristic of $-I,-T$ activation in this field, and the rise in frequency factor is appropriate for attack by an anion on a cation. While the trimethylammonium ion as a *para*-substituent also caused a considerable increase ($\times 10^{1\cdot8}$) in frequency factor, the absence of the $-T$ effect is demonstrated by a markedly smaller drop in activation energy (3500 cal.). Again some allowance must be made for the difference in sensitivity of the two series. For the *p*-nitro-group the activation energy changes are 13,700 and 8150 cal. lower, with frequency factors little affected, being $10^{0\cdot25}$ and $10^{0\cdot55}$ lower. An estimated lowering of activation energy of not more than 6000 cal. may thus be made for the trimethylammonium ion as a *para*-substituent into fluorobenzene, compared with 15,750 (see above) for the diazonium ion.

Experimental

Rate constants were measured as in our previous papers at not less than three temperatures (20—40° range usually) for each compound. Values of k_2 were obtained graphically, and those of the Arrhenius parameters by a least-squares analysis of not less than six separately determined values of $\log_{10} k_2$ and reciprocal temperature. Estimated probable error in activation energy (E) is $\pm$400 cal. and of $\log_{10} B$ (frequency factor) $\pm$0·30, the " probable errors " by least squares being always less than this. For the diazonium ion, mainly because of the short range of temperature measurements, the probable error is larger and may be as much as about 1000 cal. in E and 1·0 in log B. For this reason calculated values at 50° and 100° for this compound were not given. In the case of fluorobenzene concentrations (0·15M) were higher than usual (0·05M) owing to the slow replacement of halogen even at 200°; also, in order to avoid waiting for infinity readings, equimolar concentrations of aromatic compound and reagent were used. As far as the runs were followed (about 50% of reaction) good second-order kinetics were obeyed, and the rate constants thus obtained fitted well the straight-line relations of $\log_{10} k_2$ and reciprocal temperature. To confirm that the reaction of the diazonium ion really was displacement of fluorine as the ion (apart from lack of visible evolution of gas) the runs at 0° were checked by determination of fluoride ion. The procedure used was that of Treadwell and Köhl,[9] involving a conductometric titration of fluoride against aluminium in aqueous alcohol, and in which the presence of sodium was advantageous. The end-points nevertheless were not such as to give a high order of accuracy, and the closeness of the results to those made by the standard procedure (before and after correction for ionic-strength effects) must be regarded as somewhat fortuitous (1·72 and 1·68 $\times$ 10^{-3} after correction), though confirming the reaction as being simple displacement of fluorine. The highest temperature used for the diazonium ion was 5·2°.

Effect of Ionic Strength (μ).—By the Brönsted equation the reaction between ions of unlike charge is given by $\log k = \log k_0 + 2Az_Az_B\sqrt{\mu}$, where k = rate constant; z_A and z_B = valencies of ion and cation; A = Debye constant = $N^2e^3(\pi/500)^{1/2}/2{\cdot}3026(RDT)^{3/2}$, D being the dielectric constant of the solvent, and T the absolute temperature. On use of Albright and Gosting's values [10] of D for methanol at 25° (also for 35° and 45°) the Brönsted equation becomes $\log k = \log k_0 - 3{\cdot}786\sqrt{\mu}$. Similarly for water, Erben's equation [11] for relating D and T being used, the Brönsted equation at 86·8° becomes $\log k = \log k_0 - 1{\cdot}186\sqrt{\mu}$. Rates were determined experimentally at five ionic strengths for the anilinium salt at 25° in methanol, and at three ionic strengths at 86·8° in water.

With methanol a curve was obtained, which approximated to two intersecting straight lines with slopes 2·50 up to $\sqrt{\mu}$ = 0·159, and 0·570 for higher values. With water a straight line with slope 0·239 was obtained to values of $\sqrt{\mu}$ as low as could be measured. The curvature for methanol was as expected, and differences between initial slopes and theoretical values may be ascribed, at least partly, to ions' being non-spherical and to distance of the charge from the point of attack. Since the Debye constant A may be written as $B/(DT)^{3/2}$, and corresponding values of D and T are known, corrections were readily made at other temperatures. In view of

[9] Treadwell and Köhl, *Helv. Chim. Acta*, 1925, **8**, 500; 1926, **9**, 470.
[10] Albright and Gosting, *J. Amer. Chem. Soc.*, 1946, **68**, 1063.
[11] Erben, *Bull. Soc. chim. France*, 1951, 515.

the similarity in shape of the diazonium and anilinium ions as regards relative position of halogen and N^+, analogous (and in any case small in water) corrections could be made for the diazonium salt. All slopes are in the theoretical direction.[13]

Tables 3 and 4 give the values of $\log_{10} k$ and $\sqrt{\mu}$ used for the anilinium ion in methanol at 25° and in water at 86·8°, respectively.

TABLE 3. *Anilinium salt in methanol at 25°.*

$-\log_{10} k$	$\sqrt{\mu}$	$-\log_{10} k$	$\sqrt{\mu}$
3·3299	0·340	3·2157	0·167
3·3228		3·1534	0·132
3·3144		3·0571	0·093$_5$
3·2746	0·242		

TABLE 4. *Anilinium salt in water at 86·8°.*

$-\log_{10} k$	$\sqrt{\mu}$	$-\log_{10} k$	$\sqrt{\mu}$
2·7214	0·268	2·6973	0·147
2·7359		2·7013	
		2·6921	0·115

A typical run, the anilinium salt at 25·0° with OMe^- in methanol, is given as Table 5, and the full set of rate constants for the same compound is shown as Table 6. Corrections to zero ionic strength are not included in these two Tables.

TABLE 5. *Anilinium salt with* OMe^- *in methanol at* 25·0°.

Titration values ...	9·31	9·98	10·59	10·96	11·65	12·04	12·39	12·87	13·20	15·86
log term	0·1438	0·1575	0·1725	0·1831	0·2069	0·2234	0·2407	0·2694	0·2936	—
Time (hr.)	0	1	2	3	4·5	6	7·5	9·4	11·5	∞

$k_2 = 4{\cdot}76_8 \pm 0{\cdot}04_2 \times 10^{-4}$ l. mole^{-1} sec.$^{-1}$.

TABLE 6. *Anilinium salt with* OMe^- *in methanol* ($\mu = 0{\cdot}116$).

$10^5 k_2$	46·8	47·6	48·5	150	155	441	443	439	434	454
Temp.		25·0°			35·2°			44·95°		45·5°

Preparation of Materials.—Commercial fluorobenzene was purified by distillation and had b. p. 85—85° (lit. 84—85°). *p*-Fluoronitrobenzene was prepared as in Part VII.[13]

p-Fluorobenzenediazonium borofluoride. *p*-Fluoronitrobenzene was reduced with iron filings and methanol containing 10% (v/v) of hydrochloric acid (conc.). The diazonium borofluoride was made in the usual way from the crude reduction product (obtained in 59% yield), and recrystallised from acetone–ether below 40°. The product had m. p. 154·5° (decomp.) [lit. 154·5° (decomp.)].

o-Bromonitrobenzene was prepared as in Part XIV.[8] 4-Bromo-*NN*-dimethyl-3-nitroaniline was made from dimethylaniline by bromination[14] and nitration by Clemo and Smith's method[15] except that absolute nitric acid was used.

4-Bromo-NNN-trimethyl-3-nitroanilinium picrate and chloride. These were made from the tertiary amine by the method used by Zaki and Fahim[16] for a similar compound. The *picrate*, recrystallised from water, had m. p. 189·5° (sealed tube) (Found: N, 14·4. $C_{15}H_{14}O_9N_6Br$ requires N, 14·4%). The chloride, recrystallised from methanol–ether, had m. p. 179° (sealed tube).

1-Bromo-2 : 4-dinitrobenzene was made as described in Part III.[7]

UNIVERSITY OF WESTERN AUSTRALIA, NEDLANDS, W.A. [*Received, February 24th*, 1955.]

[13] Cf. La Mer and Kammer, *J. Amer. Chem. Soc.*, 1931, **53**, 2832.
[13] Briner, Miller, and (in part) Liveris and Lutz, *J.*, 1954, 1265.
[14] Cumming, Hopper, and Wheeler, "Systematic Organic Chemistry," Constable and Co., London, 1931, p. 353.
[15] Clemo and Smith, *J.*, 1928, 2421.
[16] Zaki and Fahim, *J.*, 1942, 270.

149. *Perfluoroalkyl Compounds of Nitrogen. Part II.* The Vibrational Assignment of Trifluoronitrosomethane.*

By (Mrs.) J. Mason (Miss J. Banus) and J. Dunderdale.

The infrared spectrum of gaseous trifluoronitrosomethane has been examined in the region 3800—420 cm.$^{-1}$. Eight of the observed bands have been assigned to ten of the possible twelve fundamental vibrational modes. The frequency of a further fundamental vibration has been inferred from the evidence of combination bands and overtones. The spectrum gives no information as to the magnitude of the CN torsional frequency.

Improved methods of preparation and physical constants are given for the nitroso-compounds.

The preparation of perfluoronitrosoalkanes by the action of ultraviolet light on gaseous mixtures of the alkyl iodide and nitric oxide at just under atmospheric pressure, in the presence of mercury, was described in Part I * (where a historical account supplementing that given by Barr and Haszeldine [1] can be found). Spectroscopic examination of the products confirmed the suspicion, which was mentioned in the case of trifluoronitrosomethane, that they were still impure after repeated purifications with the methods then available (ampoule-to-ampoule distillation, and low-temperature filtration through a constriction in the case of trifluoronitrosomethane, and distillation with −78° reflux in the case of heptafluoro-1-nitrosopropane), and steps were taken to improve the products for spectroscopy and for determination of better physical constants.

First, the apparatus for irradiation was improved, so that the reaction time was reduced from 2—3 hr. to 15 min. [cf. 3—7 days (Haszeldine [2]), or 20—25 hr. (Barr and Haszeldine [1])], which improved the purity since the nitroso-compounds are unstable to light. It was found, too, that the reaction proceeds as well, if not better, in the absence of mercury. A globule of mercury was added in the earlier experiments to remove iodine, and it also removes dinitrogen tetroxide, the presence of which would reduce the yield of nitroso-compound considerably; however, mercury does this very inefficiently unless the vessel is shaken, in which case the yield is very poor, probably because of photo- or photo-sensitised reaction (the reaction with mercury is very slow in the dark †). But very little dinitrogen tetroxide is formed if the apparatus is leak-tight and if the irradiation time is short, so the mercury served no useful purpose, since the reaction is not reversible.

Next, a simple apparatus (see Fig. 1) was designed for the filtration of trifluoronitrosomethane at liquid-air temperatures, and from this it was possible to isolate a pure sample of the contaminant persisting after distillation. This gas had a molecular weight of 44, and sublimed at about −80°, and in the crystalline state resembled carbon dioxide; but it was insoluble in alkali, and infrared spectroscopy showed it to be nitrous oxide. This could be formed during the preparation of nitric oxide, or by the action of ultraviolet light on nitric oxide or trifluoronitrosomethane. Since nitrous oxide boils at −88·5° (m. p. −90·9°) and is very inert it is not surprising that a complete separation had not been effected.‡

* Part I, *J.*, 1953, 3755.

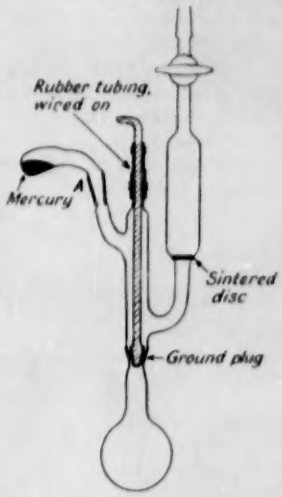
† The experiment to which Barr and Haszeldine [1] take exception, in which trifluoronitrosomethane was completely decomposed by being shaken with mercury for 20 hr. (Banus [3]) was performed without exclusion of light. Its relevance is to the preparative method described by Haszeldine,[2] in which the fluoroiodide was shaken with excess of mercury and nitric oxide in a silica vessel with ultraviolet irradiation for 3—7 days, after which it is claimed that there was a 75% "yield" of trifluoronitrosomethane, the conversion of iodide into nitroso-compound being given as 10% (*i.e.*, a 10% yield of trifluoronitrosomethane, 13% of the iodide being consumed and 87% recovered). The static method of preparation is much superior to irradiation with shaking, and the omission of mercury altogether is best of all.

‡ *E.g.*, the spectrum (C.S. no. 82) deposited by Jander and Haszeldine [4] with the Chemical Society shows their specimen to contain the impurities, nitrous oxide and trifluoroiodomethane (the former probably still unsuspected by them, the latter acknowledged later [1]), which delayed our determination of good physical constants and infrared spectra.

[1] Barr and Haszeldine, *J.*, 1955, 1881.
[2] Haszeldine, *J.*, 1953, 2075.
[3] Banus, *J.*, 1953, 3755.
[4] Jander and Haszeldine, *J.*, 1954, 912.

Purification of trifluoronitrosomethane by gas chromatography was therefore chosen. Nitrous oxide, of which the critical diameter, since it is linear, is presumably that of nitrogen (*ca.* 3 Å) would be expected to be sorbed more readily in intercrystalline channels than trifluoronitrosomethane, of which the critical diameter would be nearer 5 Å (cf. 4·94 for CF_3Cl, 4·84 for CHF_3, according to Barrer and Brook [5]). A separation was effected by the use of Doucil, a sodium aluminosilicate gel (J. Crosfield and Sons, Ltd.).

FIG. 1.



For gas chromatographic purposes, Doucil was ground, degassed *in vacuo* at 240° for 24 hr., and used as a sorbent at −80°. The nitrous oxide was adsorbed, probably on internal surfaces, as well as coloured impurities and about 5% of the trifluoronitrosomethane, probably on external surfaces. The trifluoronitrosomethane that passed through was spectroscopically pure, except for a trace of nitrous oxide. The sorbate was released at diminished pressure at room temperature.

Other sorbents may be more selective than Doucil, which has a wider distribution of pore sizes than, in particular, zeolites. However, chabazite, for example, appears to promote an unusual reactivity in the sorbate (*e.g.*, the dehydrohalogenation of chlorodifluoromethane [5]) and trifluoronitrosomethane is in any case a very reactive compound.* A recent report [8] (which appeared after the work described here was done) states that nitric oxide readily disproportionates on chabazite, which adsorbs it strongly, but not on Doucil, which adsorbs it less strongly.

Trifluoronitrosomethane was distilled through an improved low-temperature column, shielded from light and with −80° reflux. Vapour-pressure equations for the purified nitroso-compounds are :

$CF_3{\cdot}NO$: $\log p$ (mm.) $= 7{\cdot}690 - 907{\cdot}2/T$, giving b. p. (extrapolated) −84·5°, L_e 4133 cal., and Trouton coefficient 21·9.

$C_3F_7{\cdot}NO$: $\log p$ (mm.) $= 8{\cdot}077 - 1364{\cdot}2/T$, giving b. p. (extrapolated) −11·5°, L_e 6225 cal., and Trouton coefficient 23·8.

Assignment of the Vibrational Frequencies.—The trifluoronitrosomethane molecule is bent and so belongs to the symmetry point group C_s (cf. methanol [9]). Hence there should be twelve fundamental vibrations, all infrared and Raman active, eight of which will be symmetric with respect to the plane of symmetry (species *A'*) and four antisymmetric (*A''*). However it is likely that twelve distinct frequencies will not in practice be observed. If the C·N:O group were linear, the molecule would belong to the point group C_{3v} and would have four singly and four doubly degenerate vibrations; the lowering of symmetry due to the non-linearity of this group will not necessarily cause any considerable splitting of the frequencies corresponding to the modes which would be degenerate in the more symmetrical case. In the present assignment there are two such frequencies which appear not to be split.

Table 1 lists the frequencies observed in the region 3800—420 cm.$^{-1}$ for gaseous

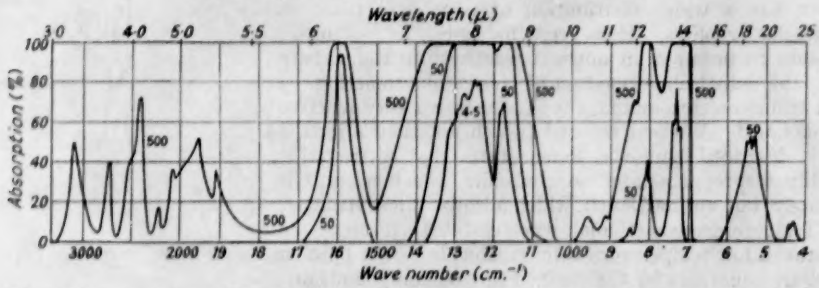
* Barr and Haszeldine [1] describe as " completely fallacious " the statements by Banus [3] about the decomposition of perfluoronitrosoalkanes at room temperature. We re-affirm the reality of this decomposition : it is rapid in standard apparatus, accelerated by light, much slower in the dark, giving, *inter alia*, nitrous oxide, and the orange compound originally described by Jander and Haszeldine [6] as $(CF_3)(CF_3{\cdot}O)N{:}NO$ (but see Tarte [7]).
The difficulties of working with perfluoronitrosoalkanes, namely, low yields and impure products, have now largely been overcome.

[5] Barrer and Brook, *Trans. Faraday Soc.*, 1953, **49**, 940.
[6] Jander and Haszeldine, *J.*, 1954, 696.
[7] Tarte, *J. Chem. Phys.*, 1955, **23**, 979.
[8] Addison and Barrer, *J.*, 1955, 757.
[9] Herzberg, " Infrared and Raman Spectra," Van Nostrand, New York, 1945, p. 334.

trifluoronitrosomethane (Fig. 2). A spectrum of this compound was published [4] after these results were obtained. There is general agreement between this spectrum, which covered only the sodium chloride region, and ours, except that weak bands observed at *ca.* 2210, 1835, 1460, 1115, 1028, and 976 cm.$^{-1}$ were not found by us in pure samples, though we did observe bands at 1835, 1028, and 976 cm.$^{-1}$ in impure samples; the band at 2210 cm.$^{-1}$ in Jander and Haszeldine's spectrum appears to form a doublet with the band at 2227 cm.$^{-1}$, and is probably due to the presence of nitrous oxide.[10] This spectrum does not show bands observed by us at 903, 1237, and 1310 cm.$^{-1}$.

Four sets of values for the moments of inertia of trifluoronitrosomethane were calculated, from assumed molecular dimensions, and the symmetry factors ρ and S, described by Badger and Zumwalt [11] were then evaluated. From these the separation of the P and the R branch were calculated for each of the band types A, B, and C, which correspond to electric moments or changes of moment parallel to the A, B, and C axes (of least, intermediate, and greatest moment of inertia), respectively. The usefulness of this method was, however, limited, as the values of the P–R separation are rather similar for the

FIG. 2. *Infrared spectrum of trifluoronitrosomethane.*



Numerals are gas pressures (mm.). There is a slight shoulder on the low-frequency side of the band centred at 438 cm.$^{-1}$, which the diagram does not show.

different band types. Further, the A' vibrations will produce components of electric moment parallel to both the I_x and I_z axes (respectively parallel and perpendicular to the NO bond, in the CNO plane), so that such bands will be hybrids of types A and B.

Inspection of the spectrum suggests that the bands at 1590, 1181, 811, 731, 542, and 438 cm.$^{-1}$ are fundamental frequencies, and that at least one and probably two others are in the region of strong absorption between 1300 and 1230 cm.$^{-1}$.

The assignment is based largely on considerations of the probable regions of absorption appropriate to the different modes of vibration, and the work of Edgell and May [12] and of Plyler and Acquista [13] on trifluoromethyl compounds has been very helpful in the assignment of the CF vibrations. Edgell and May suggest that the "natural" frequencies of the CF_3 group, if there is not much interaction with other modes, should lie near 700 and 1100 cm.$^{-1}$ for the symmetrical deformation and the symmetrical stretching mode, respectively, and near 520 and 1180 cm.$^{-1}$ for the corresponding degenerate vibrations. The bands in the trifluoronitrosomethane spectrum at 731 and 1181 cm.$^{-1}$ are therefore assigned to the A' deformation and stretching mode, respectively, and the band at 542 cm.$^{-1}$ to the antisymmetric A'' deformation vibration. The contours of these bands are similar to those of corresponding bands in trifluoronitromethane,[14] bromotrifluoromethane, and trifluoroiodomethane.[12, 13] The degree of splitting of each degenerate vibration of the CF_3 group in trifluoronitrosomethane, to give one A' and one A'' vibration, depends on the nteraction between the two halves of the molecule. This interaction seems to be small

[10] *Op. cit.*, p. 277.
[11] Badger and Zumwalt, *J. Chem. Phys.*, 1938, **6**, 711.
[12] Edgell and May, *ibid.*, 1954, **22**, 1808.
[13] Plyler and Acquista, *J. Res. Nat. Bur. Stand.*, 1952, **48**, 92.
[14] Part III, following paper.

for the *A''* deformation, whose frequency is close to that of the same degenerate mode in trifluoro-nitro-, -bromo-, and -iodo-methane, so this frequency, 542 cm.$^{-1}$, has also been assigned to the *A'* deformation vibration.

Although Herzberg [9] considers that the internal modes of the CX_3 group are less likely to be split than those of the CX_3·YZ chain, in the present case the interaction seems to be large, for there is a considerable shift of the antisymmetrical CF stretching frequency from the "natural" frequency of 1180 cm.$^{-1}$ to the 1300—1230 cm.$^{-1}$ region. It is therefore proposed that both *A'* and *A''* frequencies, derived from the *E* stretching of CF_3, lie within this range. If we choose the band centred at 1250 cm.$^{-1}$, with the shoulder at 1237 cm.$^{-1}$ as its *P* branch, for one of these vibrations, the other could be the band centred at 1298 cm.$^{-1}$, since this band does not appear to be a combination or overtone frequency. Of the two, the band at 1298 cm.$^{-1}$ has been chosen, rather arbitrarily, as the *A''* mode, since the least symmetrical stretching vibration in CF_3 compounds usually has the higher frequency.

The only other CF frequencies to be assigned are those of the *A'* and *A''* rocking modes. The band at 438 cm.$^{-1}$ has been chosen for both of these, in view of its similarity, in position and contour, to the band assigned to the CF_3 rocking vibration in other CF_3 compounds, especially trifluoroiodomethane.[12, 13]

Of the other fundamentals, the intense absorption centred at 1595 cm.$^{-1}$ can be immediately assigned, on grounds of frequency and intensity, to the NO stretching vibration, and similarly the band centred at 811 cm.$^{-1}$ to the CN stretching vibration (cf. 800—920 cm.$^{-1}$ for the lower nitroalkanes [15] and 944 cm.$^{-1}$ suggested for trichloronitrosomethane [16]). The contours of the bands at 811 and 1181 cm.$^{-1}$ are very similar, so that the former must also arise from an *A'* mode. Evidence from overtones and combination bands points to the existence of a band at about 405 cm.$^{-1}$, which has been assigned to the C·NO deformation mode. The CN torsional vibration will have a fundamental frequency of about 200 cm.$^{-1}$, but no indication of the magnitude can be found in the infrared spectrum.

The remaining frequencies have been assigned as binary or ternary (below and above 1930 cm.$^{-1}$ respectively) combination bands of the 11 fundamentals. The band at 1277 cm.$^{-1}$ is stronger than one would expect; this may be due to Fermi resonance between the overtone at 1273 cm.$^{-1}$ and the fundamental at 1298 cm.$^{-1}$. The intensity of the combination band at 1273 cm.$^{-1}$ may also be enhanced by the overlapping of the *P* and the *R* branch of the bands centred at 1298 and 1250 cm.$^{-1}$ respectively.

The fundamentals are listed in Table 2, with an approximate description of the motion involved, and a complete interpretation of the spectrum is given in Table 1. No complete assignment of the heptafluoro-1-nitrosopropane spectrum has been attempted, but the following fundamental frequencies can be picked out: NO antisymmetrical stretching and symmetric stretching at 1603 and 1310 cm.$^{-1}$, CN stretching at 855 cm.$^{-1}$, and CF bending at 746 cm.$^{-1}$.

The NO stretching frequency, 1595 cm.$^{-1}$ for trifluoronitrosomethane and 1603 for heptafluoro-1-nitrosopropane is of interest, since few values were available for *C*-nitroso-compounds before Tarte's work; [16] Bellamy [17] favoured the 1420—1310 cm.$^{-1}$ region for this vibration. Tarte lists the NO stretching frequencies for gaseous compounds, and these accord better with our findings; CCl_3·NO 1621; $R_2C(NO)Cl$ 1580—1600 (R = alkyl); Me_3C·NO 1574; PhNO *ca.* 1523 cm.$^{-1}$.

The NO stretching frequencies of nitrosoalkanes lie close to the corresponding values for the lower nitroalkanes, *i.e.*, 1590—1570 cm.$^{-1}$ (Smith *et al.*[15]), slightly below the value for trifluoronitromethane.[14] However, these are all well below the NO stretching frequencies for NOX compounds: NOBr 1801 (Burns *et al.*[18]); NOCl 1800 (Pulford *et al.*[19]); NOF 1844 (Woltz *et al.*[20]); NO 1876 cm.$^{-1}$ (Herzberg [21]). In the nitrosyl halides

[15] Smith, Pan, and Nielsen, *J. Chem. Phys.*, 1950, **18**, 706.
[16] Tarte, *Bull. Soc. chim. belges*, 1954, **63**, 525.
[17] Bellamy, "The Infrared Spectra of Complex Molecules," Methuen, London, 1954, p. 254.
[18] Burns and Bernstein, *J. Chem. Phys.*, 1950, **18**, 1669.
[19] Pulford and Walsh, *Trans. Faraday Soc.*, 1951, **47**, 347; cf. ref. 18 and other workers.
[20] Woltz, Jones, and Nielsen, *J. Chem. Phys.*, 1952, **20**, 378.
[21] Herzberg, "The Spectra of Diatomic Molecules," Van Nostrand, New York, 1950, p. 62.

a shorter and stronger NO bond (as compared with the usual NO double bond) is correlated by Ketelaar and Palmer [22] with increased ionic character in the molecule, *i.e.*, a contribution from $X^-(N{:}O)^+$. According to this interpretation the degree of ionic character falls in the series NOF > NOCl > NOBr > CF_3·NO, as one would expect.

TABLE 1. *Description and assignment of* CF_3·NO *spectrum.*

Band ($cm.^{-1}$) *		Assignment		Band ($cm.^{-1}$) *		Assignment	
405 †		A' NO deformation		1237	s	A' {438 + 811 = 1249 {CF stretching	$A' + A''$
432	m	A' and A'' CF_3 rocking		1250			
438				—			
444·5				1277	s	731 + 542 = 1273	$A' + A''$
532	s	A' and A'' CF deformation		—	sh	A'' CF stretching	
542				1298			
550				1310			
725·8	s	A' CF deformation		1588	vs	405 + 1181 = 1586	A'
731·2				1595		A' NO stretching	
740·8				1911	vw	731 + 1181 = 1912	A'
803	s	A' {2 × 405 = 810 {CN stretching	A'	1955	vw	405 + 731 + 811 = 1947	A'
810·7				2080	vw	542 + 731 + 811 = 2084	$A' + A''$
816				2227	vw	N_2O trace	
846·8	s	405 + 438 = 843	$A' + A''$	2405	w	811 + 1591 = 2402	A'
903	vw	?		2514	vw	2 × 1250 = 2500;	A'
957	vw	405 + 542 = 947	$A' + A''$			542 + 731 + 1250 = 2523	$A' + A''$
1177	s	A' CF stretching		2741	vw	405 + 731 + 1591 = 2727	$A' + A''$
1181				3104	vw	731 + 2 × 1181 = 3093	A'
1187							

* w = weak; m = medium; s = strong; sh = shoulder; v = very.
† From combination bands.

TABLE 2. *Fundamental frequencies.* CF_3·NO, C_s.

		($cm.^{-1}$)			($cm.^{-1}$)
A'	NO stretching	1595 *	A''	CF stretching	1298
Infrared and Raman active In plane	CF stretching	1250 *	Infrared and Raman active Out of plane	CF deformation	542
	CF stretching	1181		CF_3 rocking	438
	CN stretching	810·7 *		CN torsion	*ca.* 200 (conjectural)
	CF deformation	731·2 *			
	CF deformation	542			
	CF_3 rocking	438			
	NO deformation	405 †			

* Cf. Jander and Haszeldine.[4]
† From combination bands.

EXPERIMENTAL

Trifluoronitrosomethane and Heptafluoro-1-nitrosopropane.—Trifluoroiodomethane (or heptafluoro-1-iodopropane) and nitric oxide in 1 : 1 gas mixtures at just below atmospheric pressure were irradiated for 15 min. in a Vycor tube of 53 mm. outer diameter and 30 cm. length, enclosed in a spiral mercury lamp. The lamp consisted of 24 turns of 12 mm. silica tubing, the helix being 30 cm. long and 4 cm. in outer diameter, and gave almost pure 2537 Å radiation of high intensity (see Part I). The iodine deposits (large crystals) were not removed when the reaction vessel was emptied and refilled (from a vacuum-system) for another irradiation. With such a short reaction time, the process could readily be made continuous.

The crude product was bubbled through dilute alkali to remove oxides of nitrogen, carbon dioxide, and iodine, then distilled many times through a trap cooled in melting *iso*pentane (−160°). It was further purified at −196°, where it is still liquid, though viscous, and the contaminants are solid. The gas mixture was taken from the vacuum-system into the apparatus shown in the Figure through the joint at the top, and condensed at the liquid-nitrogen level above the sintered disc. Trifluoronitrosomethane runs down through the disc into the bulb at the bottom (the ground plug being raised out of its seating), and the residual perfluoronitrosomethane above the disc is pushed through with dry gaseous nitrogen. The ground plug is then wedged tight, the bath lowered until the liquid-nitrogen surface is below the plug, and mercury quickly dropped in (by rotation of the inner joint at *A* through 180°) to seal the plug. After this the white solid material above the plug can be distilled back into the vacuum-system. This

[22] Ketelaar and Palmer, *J. Amer. Chem. Soc.*, 1937, **59**, 2629.

material is not completely separated from the deep blue trifluoronitrosomethane, which can be seen to wet it, but a completely colourless sample of the contaminants was obtained by exploiting the observation that this material sublimes at low temperatures without melting. The mixture was condensed into a small cold-finger, which was then warmed with the hand whereupon the liquid trifluoronitrosomethane, which wets the glass, evaporated, leaving some white solid for which the thermal contact with the glass was less good, identified as nitrous oxide (see p. 754). This sample was contaminated with trifluoro-nitro- and -iodo-methane, since in selecting the " purest " fractions of trifluoronitrosomethane the desired molecular weight of 99 had been used as criterion, and the impurities of higher molecular weight had balanced the nitrous oxide. A pure sample of nitrous oxide was isolated by distillation, and its identity confirmed tensimetrically (*M*, 44).

Gas-chromatographic Purification.—" Doucil " was ground and packed in a tube of 8 mm. outer diameter and 120 cm. length, bent 3 times so that it could be slid into a tubular furnace, and from there into a tubular container for solid carbon dioxide, which was crushed and moistened with ether. The sorbent was degassed *in vacuo* at 240° for 24 hr. and then held at −80° while the slightly impure trifluoronitrosomethane was passed through at about 40 mm. pressure at a rate of about 500 c.c. (S.T.P.) per hr., shielded from light. The emerging gas was analytically pure, and was used for the spectroscopic studies. A small amount of material, which was not examined, was desorbed only at higher temperatures.

Infrared Spectra.—Infrared spectra were measured at various gas pressures in a 10 cm. cell with a Hilger D 209 spectrometer (single beam), with fluorite, rock salt, and potassium bromide prisms. It is estimated that the accuracy of measurement of sharp bands is 1 cm.$^{-1}$ at low frequencies and 5 cm.$^{-1}$ at high frequencies. Additional spectra were taken by courtesy of Prof. A. Albert of the Australian National University with a 12C single-beam Perkin-Elmer recording spectrophotometer.

Some of the experimental work described was carried out (by J. M.) at the Ohio State University, Columbus, Ohio, in 1953. One of us (J. D.) thanks the Ministry of Education for a grant under the Further Education and Training Scheme. We thank Delia M. Simpson (Mrs. J. N. Agar) for much useful advice.

William Ramsay and Ralph Forster Laboratories,
University College, London, W.C.1. [*Received, July 8th*, 1955.]

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150. *Perfluoroalkyl Compounds of Nitrogen. Part III.* The Vibrational Assignment of Fluoropicrin, Chloropicrin, and Bromopicrin.*

By (Mrs.) J. Mason (Miss J. Banus) and J. Dunderdale.

The infrared spectrum of gaseous fluoropicrin has been examined in the region 3000—420 cm.$^{-1}$. Ten of the observed bands have been assigned to twelve fundamental modes, two further modes have been assigned to a frequency beyond the range of this investigation on the evidence of combination bands and overtones, and the frequency of the infrared forbidden CN torsional vibration has been inferred from overtone evidence.

These assignments are supported by correlation of the fundamental frequencies of the molecules $CX_3{\cdot}NO_2$, where X is H, D, F, Cl, Br. The infrared spectra of liquid and gaseous chloropicrin and bromopicrin have been observed in the region 1800—450 cm.$^{-1}$, and some corrections have been made to previous assignments.

The preparation of fluoropicrin has been described in Part I of this series.[1] Infrared spectra were taken at various gas pressures in a 10 cm. cell with a Hilger D 209 spectrometer (single beam), or with a 12C single-beam Perkin-Elmer recording spectrophotometer, with fluorite, rock-salt, and potassium bromide prisms. The gas cell was heated electrically for the spectra of chloropicrin and bromopicrin in the vapour state, and for liquid-phase spectra a sandwich cell was used.

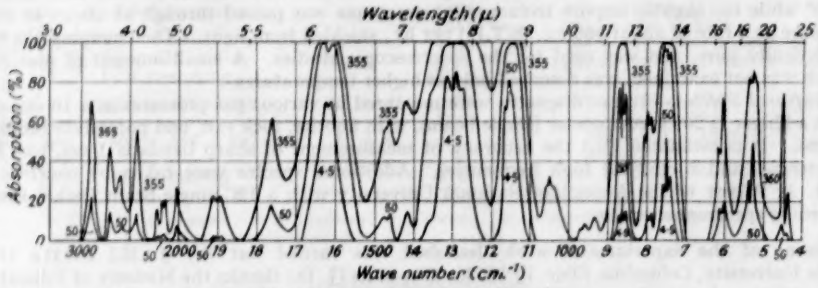
* Part II, preceding paper.

[1] Banus, *J.*, 1953, 3755.

Assigment of the Vibrational Frequencies of Fluoropicrin.—Molecules of the type $CX_3{\cdot}NO_2$, *e.g.*, halogenopicrins, have effectively the symmetry of the C_{2v} point group, *i.e.*, the symmetry of the NO_2 group, as shown by Wells and Wilson [2] for nitromethane. The fifteen fundamental modes are distributed between the four symmetry classes A_1, A_2, B_1, and B_2, and all should be Raman active. With the exception of the CN torsional vibration, the sole member of the symmetry class A_2, all the fundamental modes are also allowed in the infrared spectrum.

However, fourteen distinct fundamental frequencies will not necessarily be observed, since the interaction between the CF_3 group and the less symmetrical NO_2 group may not be sufficient to split the frequencies corresponding to the degenerate CF_3 modes [cf. the CH unsymmetrical stretching vibrations in nitromethane [2,3] and the A' CF deformation vibrations in $CF_3{\cdot}NO$ (Part II)].

FIG. 1. *Infrared spectrum of fluoropicrin.*



Numerals are gas pressures (mm.).

The frequencies observed (Fig. 1) for gaseous fluoropicrin, $CF_3{\cdot}NO_2$, in the region 3000—420 cm.$^{-1}$ are listed in Table 1, together with an approximate description of the bands, and their assignment. A spectrum of fluoropicrin was published by Jander and Haszeldine [5] after the present results were obtained. There is general agreement between this spectrum, which covered only the NaCl region, and ours, except that weak bands observed at *ca.* 1000 and 1500 cm.$^{-1}$ were not found by us, and we observed additional weak bands at 936, 961, and 969 cm.$^{-1}$.

If the following molecular dimensions are assumed : [6] CF 1·33 Å; ∠FCF 108° 30′; CN 1·44 Å; NO 1·21 Å; ∠ONO 127°, then the moments of inertia are 209×10^{-40}, 303×10^{-40}, and 366×10^{-40} g. cm.^{2}. The axis of smallest moment of inertia is coincident with the CN bond, and the axis of intermediate moment lies in the plane of the NO_2 group irrespective of the position of the oxygen relatively to the fluorine atoms. The values of Badger and Zumwalt's symmetry factors [7] ρ and S are 0·62 and −0·45 respectively. The values calculated from these for the separation of the P and the R branch maxima for each of the contour types A, B, and C, are given, together with the observed values, in Table 2.

Three of the class A_1 bands, those centred at 863, 751, and 1154 cm.$^{-1}$, are readily recognised from their type A contour. Of these, the second and third can immediately be assigned as they are close to the frequencies suggested by Edgell and May,[8] namely, 700 and 1100 cm.$^{-1}$, for the "natural" CF symmetrical deformation and stretching vibration respectively. Similarly, the frequencies of the NO_2 symmetrical stretching and deformation modes are well established,[3,9] and the bands centred at 1315 and 604 cm.$^{-1}$

[2] Wells and E. B. Wilson, *J. Chem. Phys.*, 1941, **9**, 314.
[3] Smith, Pan, and Nielson, *J. Chem. Phys.*, 1950, **18**, 706.
[4] Mason and Dunderdale, preceding paper.
[5] Jander and Haszeldine, *J.*, 1954, 912.
[6] (CF and ∠FCF) Bowen, *Trans. Faraday Soc.*, 1954, **50**, 444; (others) ref. 3.
[7] Badger and Zumwalt, *J. Chem. Phys.*, 1938, **6**, 711.
[8] Edgell and May, *ibid.*, 1954, **22**, 1808.
[9] Wittek, *Z. phys. Chem.*, 1942, **51**, *B*, (*a*) 103, (*b*) 187.

TABLE 1. *Description and assignment of* $CF_3 \cdot NO_2$ *spectrum.*

Band (cm.$^{-1}$) *		Assignment		Band (cm.$^{-1}$) *		Assignment	
220 †		CN torsion	$[A_2]$	1277	vs	CF asym. stretching	B_2
400 †		NO_2 rocking	$B_1 + B_2$			751 + 529 = 1280	$B_1 + B_2$
438·5	m	2 × 220 = 440	A_1	1288	vs	CF asym. stretching	B_1
450·2	s	CF_3 rocking	$B_1 + B_2$	1315	vs	NO sym. stretching	A_1
520						863 + 450 = 1313	$B_1 + B_2$
529	s	CF asym. deformation	$B_1 + B_2$	1330	sh	529 + 2 × 400 = 1329	$B_1 + B_2$
538·5				1353	sh	604 + 751 = 1355	A_1
—				1418	w	604 + 2 × 400 = 1404	A_1
604	s	NO sym. deformation	A_1			604 + 400 + 400 = 1404	$[A_2]$
616		400 + 220 = 620	$B_1 + B_2$	1461	w	604 + 863 = 1467	A_1
744·5				1476	w		
751	vs	CF sym. deformation	A_1	1614	s	NO asym. stretching	B_1
757		529 + 220 = 749	$B_1 + B_2$	1626		863 + 751 = 1614	A_1
790·5				1754	w	604 + 1154 = 1758	A_1
797·5	m	2 × 400 = 800	A_1	1869	vw	604 + 1277 = 1881	B_2
802		400 + 400 = 800	$[A_2]$	1913	vw	604 + 1315 = 1919	A_1
855		400 + 450 = 850	$A_1\,[A_2]$			751 + 1154 = 1905	A_1
863	m	CN stretching	A_1	2020	vw	1154 + 863 = 2017	A_1
871						1620 + 400 = 2020	$A_1\,[A_2]$
936·5	vw	400 + 529 = 929	$A_1\,[A_2]$	2145	vw	529 + 1620 = 2149	$A_1\,[A_2]$
961	vw	220 + 751 = 971	$[A_2]$			863 + 1277 = 2140	B_2
969	vw	450 + 529 = 979	$A_1\,[A_2]$	2160	vw	1288 + 863 = 2151	B_1
1042		450 + 604 = 1054	$B_1 + B_2$	2220	vw	604 + 1620 = 2224	B_1
1049	m	2 × 529 = 1058	A_1	2430	w	1154 + 1288 = 2442	B_1
1056		529 + 529 = 1058	$[A_2]$			1154 + 1277 = 2431	B_2
1148				2595	vw	1277 + 1315 = 2592	B_2
1154	vs	CF sym. stretching	A_1			1288 + 1315 = 2603	B_1
—	sh	751 + 400 = 1151	$B_1 + B_2$	2704	w	220 + 863 + 1620 = 2703	B_2
1165				2902	w	1288 + 1620 = 2908	A_1

* w = weak; m = medium; s = strong; sh = shoulder; v = very.
† Not observed; postulated from combination bands and overtones. [ ] = Forbidden species.

TABLE 2. *The fundamental vibrations of fluoropicrin, chloropicrin, and bromopicrin,* C_{2v}.

Symmetry class	Vibrational mode	$CF_3 \cdot NO_2$ Cm.$^{-1}$	*CT* [b]	*PR* sepn. (cm.$^{-1}$) calc.	*PR* sepn. (cm.$^{-1}$) obs.	$CCl_3 \cdot NO_2$ Cm.$^{-1}$	*CT* [b]	*PR* sepn. (cm.$^{-1}$) obs.	$CBr_3 \cdot NO_2$ Cm.$^{-1}$	*CT* [b]	*PR* sepn. (cm.$^{-1}$) obs.
A_1	NO sym. str.	1315 [d]	A	12·4	—	1311	B	—	1311	C	—
Totally sym.	CN sym. str.	863 [d]			16	848		18	840		9
Raman active	NO sym. def.	604			12	—		—	617·5		15
Infrared active	CX sym. str.	1154 [d]			12	439 [c]		—	302 [c]	—	
Polarised	CX sym. def.	751 [d]			12·5	296 [c]		—	212 [c]	—	
A_2	CN torsion	[220] [c]	—	—	—	—	—	—	—	—	—
Asym.											
Raman active											
Infrared inactive											
Depolarised											
B_1	NO asym. str.	1620 [d]	B	14·6	12	1625	A	15	1606	A	—
In NO_2 plane	CX asym. str.	1288			—	677		12	617·5		15
Raman active	CX asym. def.	529			18·5	202 [c]		—	138 [c]		—
Infrared active	CX_3 rocking	450			—	287 [c]		—	190 [c]		—
Depolarised	NO_2 rocking	400 [c]			—	412 [c]		—	394 [c]		—
B_2	CX asym. str.	1277	C	19·8	—	717	C	—	669	B	—
Perp. to NO_2 plane	CX asym. def.	529			18·5	202 [c]		—	138 [c]		—
Raman active	CX_3 rocking	450			—	287 [c]		—	190 [c]		—
Infrared active	NO_2 rocking	400 [c]			—	412 [c]		—	394 [c]		—
Depolarised											

[a] Liquid-phase Raman frequencies observed by Wittek.[8a] [b] Contour type (Badger and Zumwalt [7]).
[c] Postulated from combination bands and overtones. [d] In general agreement with Jander and Haszeldine,[8] who, however, assign the triplet 1310, 1285, 1270 cm.$^{-1}$ to the NO symmetric deformation mode, and do not state whether the CF stretching vibration at 1151 cm.$^{-1}$ is symmetric or asymmetric.
[ ] = Forbidden species.

are assigned accordingly. The unusual contour of the latter may be due to merging of the P and the Q branch, since the resolving power of the spectrometer is less good in this region. The only remaining fundamental belonging to symmetry species A_1 is the symmetrical CN stretching mode, which must be represented by the band centred at 863 cm.$^{-1}$; this is found between 800 and 920 cm.$^{-1}$ in the lower nitroalkanes.[3]

There is only one band which can be said to possess a type B contour [7] and that is the doublet at 1613 and 1626 cm.$^{-1}$. This must represent the NO_2 asymmetric stretching frequency. The group of bands at *ca.* 1280 cm.$^{-1}$ will contain the CF asymmetric stretching frequencies. The bands at 1277 and 1288 cm.$^{-1}$ have been chosen for these fundamentals, and on the evidence of combination bands the band at the higher frequency has been assigned to the B_1 mode. Although the band at 542 cm.$^{-1}$ seems to have the contour of a type C band, it has been chosen to represent both the B_1 and the B_2 CF asymmetric deformation modes, as in the cases of chloropicrin and bromopicrin [9a] and trifluoronitrosomethane.[4]

The band envelope in the neighbourhood of 440 cm.$^{-1}$ is not as one would expect for branches of the same band, and is probably due to two different vibrations. It is unlikely that the frequencies of the CX_3 rocking modes will be split in fluoropicrin, since they are not split in chloropicrin or bromopicrin,[9a] and are split only to a very small extent in nitromethane.[3] In view of the relative intensities of the two shoulders, it is suggested that the band at 438·5 cm.$^{-1}$ is the first overtone of the inactive CN torsional vibration. The CN fundamental should thus occur at *ca.* 220 cm.$^{-1}$. Some combination bands appear to suggest such a value for this frequency, although they can all be explained otherwise, *e.g.*, 270$\frac{1}{2}$ cm^{-1}. may be a difference frequency ($2 \times 1620 - 529$). The band at 450 cm.$^{-1}$ is then assigned to the B_1 and the B_2 CF_3 rocking mode.

An alternative possibility is that one of the bands in the region of 440 cm.$^{-1}$ may arise from one of the NO_2 rocking modes, but in view of the apparent degeneracy of these modes in chloro- and bromo-picrin we prefer to assign both the NO_2 rocking modes in fluoropicrin to a possible band at *ca.* 400 cm.$^{-1}$, with the band centred at 797·5 cm.$^{-1}$ as its first overtone. This band has a type A contour, and is therefore of symmetry class A_1, and does not appear to be due to a fundamental vibration or to a combination of these. Such a frequency would meet the requirements of several combination bands. Since the combination bands provide no evidence of another fundamental frequency, it is suggested that both the B_1 and the B_2 rocking mode would give rise to a band at 400 cm.$^{-1}$.

This assignment is further supported by a consideration of the series $CX_3{\cdot}NO_2$, where X is H, D, F, Cl, or Br.

Correlation of the $CX_3{\cdot}NO_2$ *Fundamentals.*—For nitromethane and trideuteronitromethane the assignments by Smith *et al.*[3] and Wilson,[10] respectively, have been adopted without change, except that the symmetric CH deformation and the symmetric NO stretching frequencies in nitromethane have been interchanged, to give better sequences. This alternative interpretation was mentioned by Smith *et al.*

The Raman spectra of liquid chloropicrin and bromopicrin have been reported by Wittek [9a] and by Pendl, Reitz, and Sabathy,[11] the Raman and infrared spectra by Mathieu and Massignon,[12] and the infrared spectra (sodium chloride region) by Haszeldine.[13] No vapour-phase spectra have been published. Wittek [9] has given the only complete assignment, assuming C_s symmetry, but more recent work shows several changes to be necessary. Spectra were accordingly observed for both compounds, in the vapour state at various pressures, and in the liquid state, for the region 1800—450 cm.$^{-1}$. The frequencies are listed in Tables 3 and 4, together with the Raman and infrared frequencies observed for these compounds in the liquid phase by Wittek.

The moments of inertia, the symmetry factors,[7] and the separations of the P and the R branch maxima were calculated for chloropicrin and bromopicrin. The CN bond is coincident with the z axis, and the y axis lies in the plane of the NO_2 group; the following

[10] T. P. Wilson, *J. Chem. Phys.*, 1943, **11**, 361.
[11] Pendl, Reitz, and Sabathy, *Proc. Indian Acad. Sci.*, 1938, **8**, *A*, 508.
[12] Mathieu and Massignon, *Ann. Physique*, 1941, **16**, 5.
[13] Haszeldine, *J.*, 1953, 2525.

molecular dimensions were assumed: [14] (*a*) CCl 1·76; CBr 1·92; CN 1·46; (*b*) NO 1·21; ∠ONO 127°; (*c*) ∠ClCCl 112°; ∠BrCBr 111°. The results of the band envelope calculations are given in Table 5. The contours of several bands are distinctive for particular symmetry species, and this has been helpful in deciding assignments.

The intensity distribution in each spectrum is unusual, for many of the combination bands or overtones are stronger than the fundamentals; *e.g.*, the doublet at *ca.* 870 cm.$^{-1}$ is the strongest band in the spectrum of chloropicrin, and the band at 810 cm.$^{-1}$ is the

TABLE 3. *Frequency assignment of the vibrational spectrum of chloropicrin.*

Infrared, vapour (cm.$^{-1}$)	Infrared, liquid (cm.$^{-1}$)	Raman,[a] liquid (cm.$^{-1}$)	DP †	Assignment *	
1632 1617 vs	1610 vs	1607 [b] m	0·79	NO asym. str.	B_1
1387 w	—	—	—	296 + 412 + 677 = 1385 677 + 717 = 1394	A_1 [A_2] [A_2]
1361 1355 m 1349	1350 m	1345 m	—	2 × 677 = 1354	A_1
1311 vs	1307 s	1310 [b] s	0·49	NO sym. str.	A_1
1286 w	1277 w	1275 vw	—	439 + 846 = 1285	A_1
1243 1235 w	—	—	—	412 + 846 = 1258	B_1 B_2
1133 w	—	1105 vw	—	287 + 846 = 1133 296 + 846 = 1142 412 + 717 = 1129	B_1 B_2 A_1 A_1 [A_2]
1070 vw	—	—	—	202 + 202 + 667 = 1071	B_1 B_2
1038 vw	—	1025 vw	—	202 + 846 = 1048	B_1 B_2
1007 vw	—	—	—	287 + 717 = 1004	A_1 [A_2]
916 900 s —	895 s	910 w	—	202 + 717 = 919	A_1 [A_2]
876 868 vs	858 s	865 vw	—	2 × 439 = 878 202 + 677 = 879	A_1 A_1 [A_2]
— 853 846 840 m	842 m	843 [b] s	0·27	CN stretching	A_1
746·5 741 738 m —	733 w	—	—	296 + 439 = 735	A_1
717 s	707 m	710 s	0·70	CCl asym. str.	B_2
682·5 677 670·5 m	670 m	673 w	dp	CCl asym. str.	B_1
	523 w	516 w	—	202 + 296 = 498	B_1 + B_2
	445 m	439 [b] vs	0·09	CCl sym. str.	A_1
		412 vw	—	NO_2 rocking	B_1 + B_2
		296 s	0·66	CCl sym. deformation	A_1
		287 s	dp	CCl_2 rocking	B_1 + B_2
		202 [b] vs	0·81	CCl asym. deformation	B_1 + B_2

[a] Wittek.[9a] [b] Assignment by Wittek.[9]

* If the frequency 610 cm.$^{-1}$ is assumed for the NO symmetric deformation mode, then the following combination bands are possible: 610 + 677 = 1287 B_1; 2 × 610 = 1220 A_1; 610 + 439 = 1049 A_1; 610 + 296 = 906 A_1; 610 + 287 = 897 B_1; B_2.

† DP = depolarisation factor. dp = depolarised.

strongest in the spectrum of bromopicrin, and neither can be assigned as a fundamental. Wittek sought a special explanation for the high intensity of the band at 1345 cm.$^{-1}$ in the spectrum of chloropicrin, but in view of the other peculiarities of the intensity distribution, this is hardly necessary.

Another curious feature of the chloropicrin spectrum is the absence of a band that can be assigned to the A_1 NO_2 symmetric deformation mode. The frequency would be expected to be about 600 cm.$^{-1}$, as for the lower alkanes,[3,9b] and in the case of bromopicrin the band

[14] Pauling, "The Nature of the Chemical Bond," Cornell Univ. Press, New York, 1945, p. 164; ref. 3; ref. 14*a*, p. 84.

is at 617 cm.$^{-1}$. However there is no absorption in this region in any of the reported spectra of chloropicrin, although a fundamental at *ca.* 610 cm.$^{-1}$ would allow several further interpretations of combination bands, as shown at the end of Table 3. Wittek reports weak bands at 519 and 516 cm.$^{-1}$ in the spectra of chloropicrin and bromopicrin respectively, which were not observed by us. The former cannot be assigned as a combination band or as an overtone, and on the evidence of some of the bands at higher frequencies in each spectrum each of these frequencies could represent a fundamental. It is possible that these bands are due to the A_1 symmetric NO_2 deformation modes in chloropicrin and bromopicrin, but as the frequencies are so low, for no obvious reason, the matter must be left open.

TABLE 4. *Frequency assignment of the vibrational spectrum of bromopicrin.*

Infrared, vapour (cm.$^{-1}$)	Infrared, liquid (cm.$^{-1}$)	Raman,[a] liquid (cm.$^{-1}$)	DP	Assignment	
1606 m	1595 vs	1591 [b] s	0·74	NO asym. str.	B_1
	1540 w				
1385 m	1395 w	—	—	?	
1311 m	1307 s	1306 [b] s	0·32	NO sym. str.	A_1
845, 840, 834	840 m	840 [b] s	0·28	CN sym. str.	A_1
810 vs	805, 795 vs	799 m	—	617·5 + 190 = 807·5 669 + 138 = 807	$A_1 B_1 B_2 [A_2]$ $A_1 [A_2]$
669 m	669 w	669 m	0·75	CBr asym. str.	B_2
625, 617·5, 609·5 m	613 m	613 m	0·62	NO sym. bending CBr asym. str.	A_1 B_1
589 m	587 m	—	—	394 + 190 = 584	$A_1 [A_2]$
		516 vw	—	212 + 302 = 514	A_1
		394 [b] s	0·91	NO_2 rocking	$B_1 + B_2$
		324 vw	—	190 + 138 = 328	$A_1 [A_2]$
		302 [b] vs	0·03	CBr sym. str.	A_1
		272 vw	—	138 + 138 = 276	$A_1 [A_2]$
		212 [b] s	0·50	CBr sym. deformation	A_1
		190 s	0·77	CBr_2 rocking	$B_1 + B_2$
		138 [b] s	0·76	CBr asym. deformation	$B_1 + B_2$

[a] Wittek.[9c] [b] Assignment by Wittek.[9c]

TABLE 5. *Band envelope calculations.*

Axis	Moment of inertia about axis g.cm.^{2} × 10^{40}	Contour type for vibns. parallel to axis	Symmetry species	*PR* separation at 70°
Chloropicrin	$\rho = 0·104$; $S = 0·49$.			
x	611	*C*	B_2	13
y	550	*A*	B_1	14
z	564	*B*	A_1	18·5
Bromopicrin	$\rho = 0·26$; $S = 0·54$.			
x	1110	*B*	B_2	10
y	1047	*A*	B_1	8·5
z	1391	*C*	A_1	9·7

The nearest band to the position in which the NO_2 symmetric deformation frequency would be expected is the band at 677 cm.$^{-1}$, but this has an *A* type contour, and must be correlated with a vibration of species B_1; in any case the frequency of the NO_2 symmetric deformation mode would not be expected to be so high. The assignment of the 617 cm.$^{-1}$ band in the bromopicrin spectrum is in accord with the expected *C* type contour, and to account for the high depolarisation factor we may assign the B_1 CBr asymmetric stretching mode to this frequency as well.

The bands at 296 and 190 cm.$^{-1}$ in the spectra of chloropicrin and bromopicrin respectively were assigned by Wittek to CX *A'* and *A''* stretching modes (C_s symmetry having been assumed) as doubly degenerate vibrations. However, these frequencies are obviously far too low, when compared with values observed in other CX_3 compounds, such

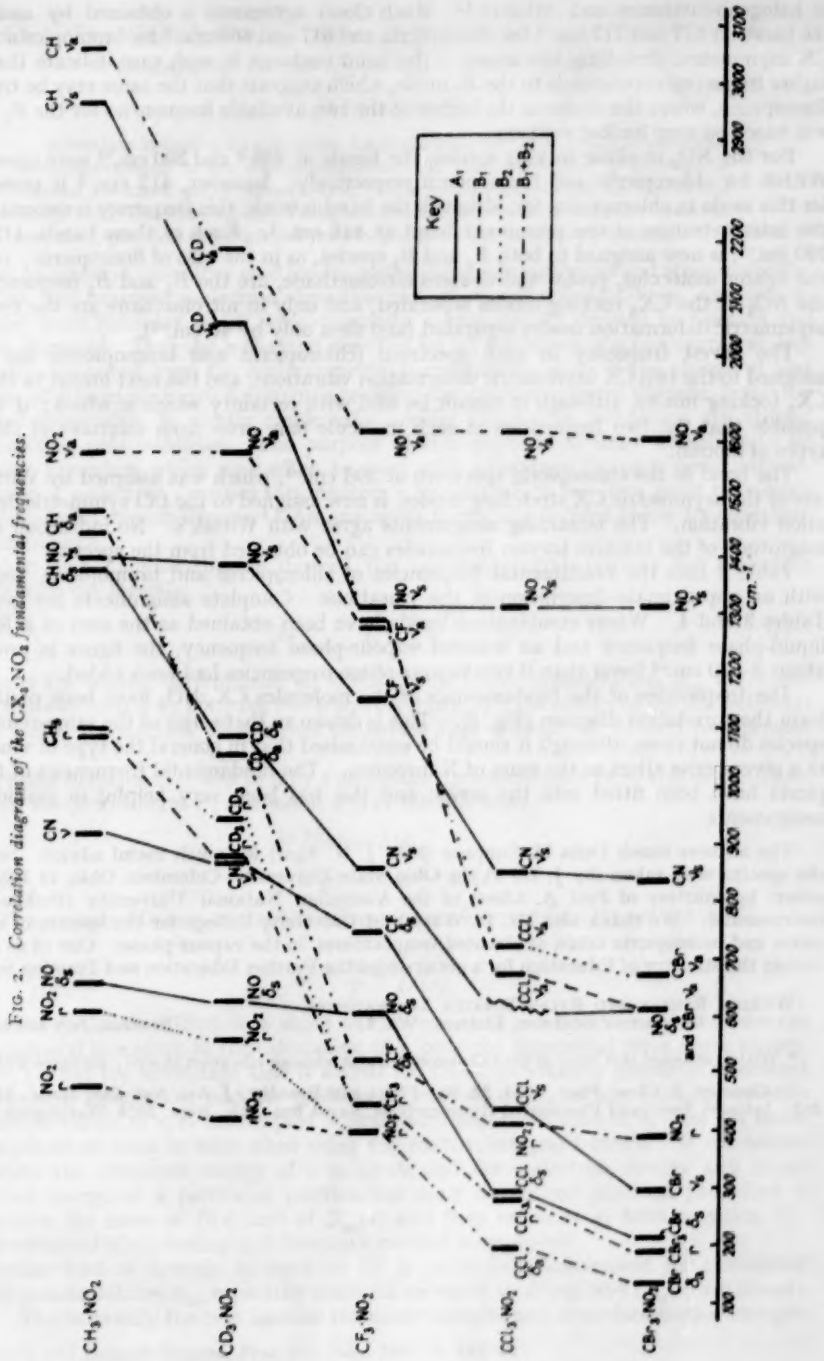


FIG. 2. *Correlation diagram of the $CX_3·NO_2$ fundamental frequencies.*

as halogeno-methanes and -ethanes.[15] Much closer agreement is obtained by assigning the bands at 677 and 717 cm.$^{-1}$ for chloropicrin and 617 and 669 cm.$^{-1}$ for bromopicrin to the CX asymmetric stretching vibrations. The band contours in each case indicate that the higher frequency corresponds to the B_2 mode, which suggests that the same may be true for fluoropicrin, where the choice of the higher of the two available frequencies for the B_1 mode was based on very limited evidence.

For the NO_2 in-plane rocking modes, the bands at 438 * and 390 cm.$^{-1}$ were chosen by Wittek for chloropicrin and bromopicrin respectively; however, 412 cm.$^{-1}$ is preferable for this mode in chloropicrin, for, although the band is weak, this frequency is necessary for the interpretration of the prominent band at 846 cm.$^{-1}$. Each of these bands, 412 and 390 cm.$^{-1}$, is now assigned to both B_1 and B_2 species, as in the case of fluoropicrin; only in the lighter molecules, proto- and deutero-nitromethane, are the B_1 and B_2 frequencies of the NO_2 or the CX_3 rocking modes separated, and only in nitromethane are the two CX asymmetric deformation modes separated (and then only by 40 cm.$^{-1}$).

The lowest frequency in each spectrum (chloropicrin and bromopicrin) has been assigned to the two CX asymmetric deformation vibrations, and the next lowest to the two CX_3 rocking modes, although it cannot be said with certainty which is which; it is also possible that the two frequencies in each molecule may arise from mixtures of the two types of motion.

The band in the chloropicrin spectrum at 296 cm.$^{-1}$, which was assigned by Wittek to one of the asymmetric CX stretching modes, is now assigned to the CCl symmetric deformation vibration. The remaining assignments agree with Wittek's. No indication of the magnitude of the inactive torsion frequencies can be obtained from the spectra.

Table 2 lists the fundamental frequencies of chloropicrin and bromopicrin, together with an approximate description of the vibrations. Complete assignments are given in Tables 3 and 4. Where combination bands have been obtained as the sum of a Raman liquid-phase frequency and an infrared vapour-phase frequency, the figure is probably about 5—10 cm.$^{-1}$ lower than if two vapour-phase frequencies had been added.

The frequencies of the fundamentals of the molecules $CX_3{\cdot}NO_2$ have been plotted to form the correlation diagram (Fig. 2). This is drawn so that series of the same symmetry species do not cross, although it should be emphasised that in general the type of vibration in a given series alters as the mass of X increases. The fundamental frequencies of fluoropicrin have been fitted into the series, and this has been very helpful in making the assignments.

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University College, London, W.C.1. [*Received, July 8th*, 1955.]

* Wittek assigned this band to the CCl symmetrical stretching vibration as well; we agree with this.

[15] Claassen, *J. Chem. Phys.*, 1954, **22**, 50; Plyler and Benedict, *J. Res. Nat. Bur. Stand.*, 1951, **47**, 202; Infrared Spectra of Fluorinated Hydrocarbons, Naval Res. Lab., Rept. 3924. Washington, 1952.

151. *The Calculation of Atom Self-polarizabilities and Similar Quantities in the Molecular-orbital Theory.*

By R. D. Brown.

Attention is drawn to a formula for π-electron densities which is often the most convenient to use for calculations. An analogous kind of formula is derived for atom self-polarizabilities. It is particularly useful for numerical work. For illustration, the atom self-polarizabilities of a benzene position and the 1-position of butadiene are evaluated by use of the new formula.

Molecular-orbital quantities used for discussing chemical reactivities and other molecular properties, for example π-electron densities and atom self-polarizabilities, are usually calculated from formulae which were originally systematically derived by Coulson and Longuet-Higgins.[1] Thus the π-electron densities for all the atoms of a conjugated system are mostly computed from the molecular-orbital coefficients, while if the charge at just one atom of a large conjugated system is required the contour-integral formula, involving numerical integration, is mostly employed. Similar alternative techniques are utilised for calculating polarizabilities. The purpose of this paper is to draw attention to an alternative procedure which may often be used with advantage for such computations. In the case of π-electron densities this involves a formula which has been given previously by Coulson and Longuet-Higgins.[1] An analogous formula is derived below for atom self-polarizabilities.

Coulson and Longuet-Higgins derived the contour-integral formula for π-electron densities from the formula

$$q_\mu = -\sum_j \nu_j \frac{\Delta_{\mu\mu}(e_j)}{\Delta'(e_j)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where Δ is the secular determinant for the molecule under consideration, $\Delta_{\mu\mu}$ the determinant derived from Δ by omitting row μ and column μ, e_j is the energy of the jth molecular orbital, and ν_j the number of electrons occupying that orbital. Δ' is used to represent $\partial\Delta/\partial e$.

It is usual to divide each row of Δ by β and make the substitution $(\alpha - e)/\beta = x$. Thus, we obtain the determinant $D(x)$ where if Δ is of the nth order

$$\beta^n D(x) = \Delta(e)$$

and then

$$\Delta'(e) = -\beta^{n-1} D'(x)$$

where D' represents $\mathrm{d}D/\mathrm{d}x$. If these relationships are inserted into (1), we obtain

$$q_\mu = \sum_j \nu_j \frac{D_{\mu\mu}(x_j)}{D'(x_j)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Practical trials reveal that it is about as convenient to use equation (2) as to use the contour-integral procedure in the calculation of q_μ once the determinal zeros x_j are known. Equation (2) has the advantage that it avoids the slight uncertainty generally associated with numerical integration, and the problem of whether there are any occupied orbitals with positive values of x_j or unoccupied orbitals with negative values of x_j does not cause any complications such as arise when using the contour-integral formula. If one wishes to calculate the resonance energy of a molecule and the π-electron density and atom-localization energy at a particular position the most convenient practical procedure is to determine the zeros of $D(x)$ and of $D_{\mu\mu}(x)$ and then calculate q_μ from equation (2); [$D'(x_j)$ is obtained while finding x_j if Newton's method is employed].

A similar kind of formula to equation (2) is particularly convenient for calculating atom self-polarizabilities, $\pi_{\mu\mu}$, especially when the values of x_j, $D'(x_j)$, and $D_{\mu\mu}(x)$ are already known. This is usually the case because resonance energies and atom-localization energies

[1] Coulson and Longuet-Higgins, *Proc. Roy. Soc.*, 1947, *A*, **191**, 39.

are generally calculated before $\pi_{\mu\mu}$ is studied. The formula may be derived from the contour-integral formula [1]

$$\pi_{\mu\mu} = \frac{1}{\pi i}\int_{\Gamma}\left\{\frac{\Delta_{\mu\mu}(\epsilon)}{\Delta(\epsilon)}\right\}^2 d\epsilon \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where the contour Γ encloses just the zeros of Δ corresponding to doubly occupied orbitals. The substitution $(\alpha - \epsilon)/\beta = x$ transforms equation (3) into

$$\pi_{\mu\mu} = \frac{-1}{\pi i\beta}\int_{\gamma}\left\{\frac{D_{\mu\mu}(x)}{D(x)}\right\}^2 dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$= -\frac{1}{\beta}\sum_j \nu_j R_j \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where R_j is the residue of the integrand in (4) at the pole x_j. The pole x_j is of the second order and, on writing $D(x) = (x - x_j)F_j(x)$, we have

$$R_j = \frac{d}{dx}\left[\left\{\frac{D_{\mu\mu}(x)}{F_j(x)}\right\}^2\right]_{x=x_j} = \frac{2D_{\mu\mu}(x_j)}{[F_j(x_j)]^3}\left\{F_j(x_j)D'_{\mu\mu}(x_j) - F'_j(x_j)D_{\mu\mu}(x_j)\right\} \quad . \quad (6)$$

From the definition of F_j we have

$$D'(x_j) = F_j(x_j); \quad D''(x_j) = 2F'_j(x_j)$$

hence equation (6) can be expressed in terms of D and its derivatives and $D_{\mu\mu}$ and its derivative. The expression (5) for the polarizability thus becomes

$$\pi_{\mu\mu} = \frac{1}{\beta}\sum_j \nu_j \frac{D_{\mu\mu}(x_j)}{[D'(x_j)]^3}\left\{D_{\mu\mu}(x_j)D''(x_j) - 2D'(x_j)D'_{\mu\mu}(x_j)\right\} \quad . \quad . \quad . \quad (7)$$

To illustrate the ease with which equation (7) can be employed the self-polarizability of the terminal atom of butadiene will be calculated.

From the secular determinants, we have

$$D(x) = x^4 - 3x^2 + 1 \text{ and } D_{11}(x) = x(x^2 - 2)$$

hence
$$D'(x) = 2x(2x^2 - 3); \quad D'_{11}(x) = 3x^2 - 2$$

and
$$D''(x) = 6(2x^2 - 1)$$

The two most negative zeros of D, and the values of the above functions at these zeros are :

x_j	D'	D''	D_{11}	D'_{11}	$-\nu_j R_j$
$-(\sqrt{5}+1)/2$	$-(\sqrt{5}+5)$	$6(\sqrt{5}+2)$	-1	$(3\sqrt{5}+5)/2$	$7\sqrt{5}/50$
$-(\sqrt{5}-1)/2$	$-(\sqrt{5}-5)$	$6(2-\sqrt{5})$	$+1$	$(5-3\sqrt{5})/2$	$7\sqrt{5}/50$

and so
$$\pi_{11} = 28\sqrt{5}/100\beta = 0{\cdot}62609903/\beta.$$

It is clear from equation (4) that we are concerned primarily with $D_{\mu\mu}/D$. If the molecule has sufficient symmetry or if accidentally D has a repeated zero then a corresponding common factor in D and $D_{\mu\mu}$ can be cancelled, thus reducing somewhat the labour of computation. The simplification occurs in the calculation of the self-polarizability of a benzene position. Thus we have

$$D = (x^2 - 1)^2(x^2 - 4) \text{ and } D_{\mu\mu} = x(x^2 - 1)(x^2 - 3)$$

and, after cancellation of the common factor,

$$D' = 2x(2x^2 - 5) \qquad D_{\mu\mu} = x(x^2 - 3)$$
$$D'' = 2(6x^2 - 5) \qquad D'_{\mu\mu} = 3(x^2 - 1)$$

These give the values

x_j	D'	D''	$D_{\mu\mu}$	$D'_{\mu\mu}$	$-\nu_j R_j$
-2	-12	38	-2	9	35/108
-1	-6	2	2	0	2/27

The self polarizability of a benzene position therefore amounts to $43/108\beta$.

It is clear from equation (5) that $-R_j/\beta$ represents the contribution of an electron in the jth orbital to the atom self-polarizability. Formula (7) may therefore prove convenient for the analysis of the relative contributions from different occupied orbitals, *e.g.*, both occupied orbitals of butadiene contribute equally to the polarizability of the 1-position.

Expressions analogous to equation (7) can similarly be derived for the other polarizabilities introduced by Coulson and Longuet-Higgins (*loc. cit.*), but less use has been made of these than of the atom self-polarizabilities. It may be noted that formula (7) is readily applicable to heterocyclic systems and non-alternant systems. The problem of whether there are any occupied orbitals with positive values of x_j or unoccupied orbitals of negative values of x_j does not cause any complications such as arise when the contour-integral formula is used.

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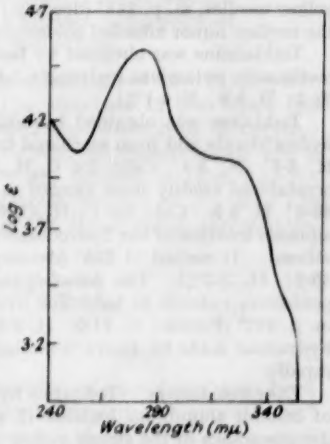
152. *Alkaloids of* Toddalia aculeata: *Identity of Toddaline with Chelerythrine.*

By T. R. GOVINDACHARI and B. S. THYAGARAJAN.

Toddaline, the major constituent of the root bark of *Toddalia aculeata*, is shown to be identical with chelerythrine, an alkaloid of the *Papaveraceae*.

FROM the root bark of *Toddalia aculeata*, Pers. (natural order Rutaceae), Perkin and Hummel [1] isolated a yellow alkaloid hydrochloride which they considered to be the salt of berberine. Subsequently, Dey and Pillay [2] established the absence of berberine in the root bark and isolated two bases named toddaline and toddalinine. According to them, toddaline was a tertiary base, $C_{17}H_{12}O_2(OMe)_2{>}NMe$, having m. p. 269—270° when crystallised from chloroform and being transformed into another modification, m. p. 204—206°, on contact with alcoholic ammonia. Toddalinine, obtained as an amorphous powder, m. p. 180—200°, was ascribed the formula $C_{17}H_9O_3(OMe){>}NMe$.



We have isolated from this root bark two pure crystalline alkaloids by a procedure less complicated than that of Dey and Pillay.[2] The first (m. p. 205°; from methanol) and its derivatives corresponded to toddaline and its derivatives. Elementary analyses of the base and its derivatives, however, necessitated a revision of the molecular formula to $C_{21}H_{19}O_5N$. The base was recovered unchanged after several hours' heating with methyl iodide and analyses of the hydrochloride and the picrate revealed their formation with elimination of a molecule of water, indicating the quaternary nature of the base. On treatment of the hydrochloride with aqueous potassium cyanide, it gave a colourless *pseudo*-cyanide, with phenylhydrazine a rather unstable hydrazone, and with zinc and hydrochloric acid a weakly basic compound, m. p. 167°, also obtained in better yield by reduction with lithium aluminium hydride. Oxidation with alkaline ferricyanide gave oxotoddaline, a neutral compound. The ultraviolet absorption spectrum (see Figure) of the alkaloid in ethanol showed a striking similarity to that of 9 : 10-dihydro-7 : 8 : 2′ : 3′-tetramethoxy-10-methyl-1 : 2-benzophenanthridine reported by Bailey, Robinson, and Staunton.[3]

[1] Perkin and Hummel, *J.*, 1895, **67**, 413.
[2] Dey and Pillay, *Arch. Pharm.*, 1933, **271**, 477.
[3] Bailey, Robinson, and Staunton, *J.*, 1950, 2277.

The alkaloid and its *pseudo*cyanide did not depress the melting points of chelerythrine and chelerythrine *pseudo*cyanide, establishing the identity of " toddaline " with chelerythrine.

The isolation of an alkaloid of the 1 : 2-benzophenanthridine group from a plant of the natural order Rutaceae wherein a variety of heterocyclic structures such as quinoline, *iso*quinoline, furanoquinoline, carboline, quinazoline, and acridine is encountered lends strong support for the suggestion by Turner and Woodward [4] that alkaloids of the berberine type (widely occurring in Rutaceae) and the 1 : 2-benzophenanthridine type have a common biogenetic origin.

Experimental

Extraction of Toddalia aculeata.—The powdered root bark (6 kg.) was extracted by percolation with cold light petroleum (b. p. 40—60°). Removal of the solvent at ordinary pressure gave a brownish oil (300 ml.), from which distillation in steam removed essential oil (41 g.). The residue was taken up in ether and washed repeatedly with 4N-hydrochloric acid, yielding the mixed hydrochlorides (5·7 g.) of toddaline and toddalinine. The ether layer after removal of all basic material was freed from solvent and hydrolysed with 10% methanolic potassium hydroxide at room temperature. The unsaponifiable portion gave β-sitosterol (1 g.). The root bark, after extraction with light petroleum, was extracted with acetone at room temperature, and the solvent from the extracts removed at ordinary pressure. The residue was repeatedly extracted with hot 10% acetic acid, the acid extract concentrated in a vacuum, and the residue taken up in ether and washed with 4N-hydrochloric acid, giving more (2 g.) of the mixed hydrochlorides. The residue, on crystallisation from benzene, yielded toddalolactone [3] (10 g.). The residue from the acetone extract after treatment with 10% acetic acid was hydrolysed as above and afforded crude toddaline (7 g.). The alkaline mother-liquor on acidification gave a new lactonic material (1·5 g.), m. p. 120°.

Separation of toddaline and toddalinine. The mixture of hydrochlorides was separated by fractional crystallisation from methanol. Toddalinine hydrochloride separated first as citron-yellow needles, m. p. 245° (decomp.) (Found : C, 65·00; H, 5·84; N, 3·8%). Concentration of the mother-liquor afforded golden-orange needles of toddaline hydrochloride.

Toddalinine was obtained by basification of a methanolic solution of its hydrochloride with methanolic potassium hydroxide. Crystallised from methanol, it had m. p. 185° (Found : C, 71·2; H, 5·6; N, 4·1%).

Toddaline was obtained by addition of sodium carbonate to an aqueous solution of the hydrochloride and from methanol formed colourless leaflets, m. p. 204—205° (Found : C, 69·3; H, 5·6; N, 3·4. Calc. for $C_{21}H_{19}O_5N$: C, 69·1; H, 5·2; N, 3·8%). The hydrochloride crystallised readily from alcohol as golden-orange needles, m. p. 210° (decomp.) (Found : C, 65·5; H, 5·3. Calc. for $C_{21}H_{18}O_4NCl$: C, 65·5; H, 4·9%). The picrate was made from an aqueous solution of the hydrochloride and was too sparingly soluble to be crystallised from any solvent. It melted at 238° (decomp.) (Found : C, 55·9; H, 3·6. Calc. for $C_{27}H_{20}O_{11}N_4$: C, 56·2; H, 3·5%). The *pseudo*cyanide, prepared by the addition of an aqueous solution of potassium cyanide to toddaline hydrochloride, crystallised from benzene as colourless prisms, m. p. 262° (Found : C, 71·0; H, 5·0. Calc. for $C_{22}H_{18}O_4N_2$: C, 70·6; H, 4·8%). The phenylhydrazone made by Karrer's method,[5] melted at 158° and was not analysed as it decomposed rapidly.

Dihydrotoddaline.—Toddaline hydrochloride (1 g.) was added to an anhydrous ether solution of lithium aluminium hydride (1 g.) with efficient stirring. The reduction was rapid with disappearance of the strong yellow colour. The mixture was stirred for a few hours after the completion of the addition and left overnight. The excess of hydride was decomposed with moist ether. The ether layer was filtered, the solvent removed, and the residue crystallised from alcohol. Colourless needles (0·55 g.) of *dihydrotoddaline*, m. p. 167°, were obtained (Found : C, 71·9; H, 5·6. $C_{21}H_{19}O_4N$ requires C, 72·2; H, 5·4%).

Toddaline hydrochloride (0·5 g.) in hot hydrochloric acid solution was reduced with zinc dust till the solution was free from colour and the strongly acidic solution was then extracted with ether. The extract, on removal of solvent, gave a colourless compound. Crystallised from alcohol, it melted at 167° and did not depress the m. p. of the specimen obtained by employing lithium aluminium hydride.

[4] Turner and Woodward, " The Alkaloids," Academic Press, Vol. III, 1953, p. 57.
[5] Karrer, *Ber.*, 1917, **50**, 212.

Oxotoddaline.—Toddaline hydrochloride (0·5 g.) was oxidised with alkaline ferricyanide as in the oxidation of sanguinarine nitrate.[6] *Oxotoddaline*, so obtained and recrystallised from methanol (0·2 g.), had m. p. 199° (Found : C, 69·8; H, 5·0. $C_{21}H_{17}O_3N$ requires C, 69·4; H, 4·7%).

We are grateful to Dr. R. H. F. Manske for the comparison of our specimen of toddaline *pseudo*cyanide with an authentic specimen of chelerythrine *pseudo*cyanide, and for the gift of a sample of chelerythrine. We thank the Government of India for a fellowship (to B. S. T.), Mr. Selvavinayagam for the microanalyses, and the Forest Department of the Government of Madras for roots of *Toddalia aculeata*.

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[6] Spath, Schlemmer, Schenck, and Gempp, *Ber.*, 1937, **70**, 1677.

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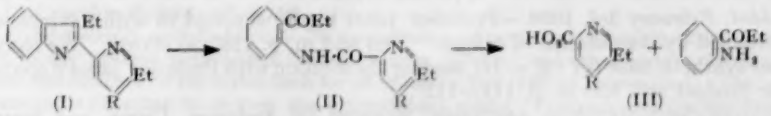
153. *The Constitution of Yohimbine and Related Alkaloids. Part IX.* Synthesis of 2-(4 : 5-Diethyl-2-pyridyl)-3-ethylindole (Alstyrine or Coryline) and Two Related Compounds.*

By T. B. LEE and G. A. SWAN.

2-(4 : 5-Diethyl-2-pyridyl)-3-ethylindole (I; R = Et) and 4 : 5-diethylpyridine-2-carboxylic acid (III; R = Et) have been synthesised and shown to be identical with the products of natural origin, *i.e.*, degradation products of the *Alstonia* alkaloids and of corynantheine. 3-Ethyl-2-(5-ethyl-2-pyridyl)-5-methoxyindole (IV; R = H) and 2-(4 : 5-diethyl-2-pyridyl)-3-ethyl-5-methoxyindole (IV; R = Et) have also been synthesised; but it was not possible to confirm the identity of the former with a product (supposedly of this structure) previously obtained by the degradation of aricine.

THE alkaloid corynantheine, on dehydrogenation with selenium, gives two oxygen-free products, coryline and de-ethylcoryline (I; R = H). The structure of the latter has been confirmed by synthesis.[1] Karrer and Enslin [2] showed that ozonolysis of coryline yielded an amide (II; R = Et), which on hydrolysis gave *o*-aminopropiophenone and a diethylpyridinecarboxylic acid, formulated as (III; R = Et) because it gave 3 : 4-diethylpyridine on decarboxylation. They therefore formulated coryline as (I; R = Et) and later [3] proved the identity of coryline and alstyrine, the latter being obtained by



(I) (II) (III)

dehydrogenation of certain *Alstonia* alkaloids.[4] More recently, alstyrine has also been obtained by the selenium dehydrogenation of the alkaloids serpentine,[5] sepentinine,[6] akuammigine,[7] β-yohimbine,[8] mayumbine,[9] and normelinonine-A.[10]

We therefore undertook the synthesis of 4 : 5-diethylpyridine-2-carboxylic acid (III;

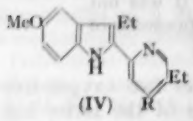
* Part VIII, *J.*, 1954, 2962.

[1] Anderson, Clemo, and Swan, *J.*, 1954, 2962.
[2] Karrer and Enslin, *Helv. Chim. Acta*, 1949, **32**, 1390.
[3] *Idem, ibid.*, 1950, **33**, 100.
[4] Sharp, *J.*, 1938, 1353.
[5] Schlittler and Schwarz, *Helv. Chim. Acta*, 1950, **33**, 1463.
[6] Schlittler, Huber, Bader, and Zahnd, *ibid.*, 1954, **37**, 1912.
[7] Robinson and Thomas, *J.*, 1954, 3479.
[8] Goutarel and Le Hir, *Bull. Soc. chim. France*, 1951, 909.
[9] Janot, Goutarel, and Massonneau, *Compt. rend.*, 1952, **234**, 850.
[10] Schlittler and Hohl, *Helv. Chim. Acta*, 1952, **35**, 29.

R = Et) and 2-(4 : 5-diethyl-2-pyridyl)-3-ethylindole (I; R = Et). 5-Ethyl-2-methylpyridine was converted into the *N*-oxide, which was nitrated to give 5-ethyl-2-methyl-4-nitropyridine *N*-oxide. The action of phosphorus tribromide on the latter yielded 4-bromo-5-ethyl-2-methylpyridine, which, when heated in an autoclave with cuprous cyanide and aqueous potassium cyanide and then esterified, yielded ethyl 5-ethyl-2-methylpyridine-4-carboxylate. Claisen condensation of this ester with ethyl acetate and subsequent hydrolysis gave 4-acetyl-5-ethyl-2-methylpyridine, which on reduction under Clemmensen conditions yielded 4 : 5-diethyl-2-methylpyridine (recently prepared by a different method by Kao and Robinson [11]). The latter product with benzaldehyde gave 4 : 5-diethyl-2-styrylpyridine, mild oxidation of which resulted in 4 : 5-diethylpyridine-2-carboxylic acid (III; R = Et), identical with that of natural origin, mentioned above. Decarboxylation of the synthetic acid gave 3 : 4-diethylpyridine, the picrate of which was identical with an authentic sample. The amide of this acid was dehydrated by phosphorus oxychloride to 2-cyano-4 : 5-diethylpyridine. Treatment of the latter with *n*-propylmagnesium bromide led to 2-butyryl-4 : 5-diethylpyridine, the phenylhydrazone of which underwent the Fischer indole reaction to give 2-(4 : 5-diethyl-2-pyridyl)-3-ethylindole (I; R = Et). The identity of the latter with alstyrine of natural origin was shown by mixed m. p. determinations as well as by ultraviolet and infrared absorption spectra.

After the above synthesis has been completed, we were informed by Sir Robert Robinson, O.M., F.R.S., that he and Mr. Robbins had carried out a rather similar synthesis of alstyrine.

By degration of aricine, Goutarel, Janot, Le Hir, Corrodi, and Prelog [12] obtained a base which they formulated as 3-ethyl-2-(5-ethyl-2-pyridyl)-5-methoxyindole (IV; R = H), because treatment with hydrogen peroxide followed by hydrolysis gave 2-amino-5-methoxypropiophenone and a mixture of 4 : 5-diethyl- and 5-ethyl-pyridine-2-carboxylic acid (the latter acid being present in greater amount than the former). We have synthesised a compound of the above structure (IV; R = H), as well as 2-(4 : 5-diethyl-2-pyridyl)-3-ethyl-5-methoxyindole (IV; R = Et); and although both these compounds have ultraviolet absorption spectra closely resembling the product of Goutarel *et al.*,[12] the melting points of the bases and picrates are not in close agreement. A mixture of our two synthetic bases resulted in a deep depression of melting point, which rules out the possibility that the product of Goutarel *et al.*[12] might be a mixture of the two. Unfortunately we have been unable to obtain a sample of the product of natural origin for comparison.



	M. p. of base	M. p. of picrate
Product from aricine	128°	233°
(IV; R = H)	111—112	201—203
(IV; R = Et)	118	225

[*Added, February 3rd*, 1956.—Professor Janot kindly supplied us with a sample of the base obtained by degradation of aricine. This had m. p. 128°, as stated. We recrystallised our synthetic base (IV; R = H), seeding the solution with Professor Janot's specimen; but the product still had m. p. 111—112°.]

2-Butyryl-5-ethylpyridine, previously prepared by Anderson, Clemo, and Swan,[1] is better obtained by the action of *n*-propylmagnesium iodide on 2-cyano-5-ethylpyridine.

Experimental

Ultraviolet absorption measurements were made with solutions in EtOH and a Hilger "Uvispec" spectrophotometer.

5-Ethyl-2-methylpyridine N-Oxide (with R. M. Anderson).—To a solution of 5-ethyl-2-methylpyridine (56 g.) in acetic acid (250 ml.) was added 30% hydrogen peroxide (54 ml.). The mixture was kept at 70° for 5 hr., then further hydrogen peroxide (40 ml.) was added and the mixture was kept at 70—80° for 15 hr. The solution was concentrated to 100 ml. under reduced pressure, diluted with water (100 ml.), and evaporated almost to dryness under reduced pressure. The residue was basified with saturated sodium carbonate solution and extracted with chloroform. Distillation of the dried (Na_2SO_4) extract gave the *N-oxide* (52 g.),

[11] Kao and Robinson, *J.*, 1955, 2865.
[12] Goutarel, Janot, Le Hir, Corrodi, and Prelog, *Helv. Chim. Acta*, 1954, **37**, 1805.

b. p. 124—128°/2 mm. (Found: C, 69·8; H, 8·0. $C_8H_{11}ON$ requires C, 70·1; H, 8·0%). The *picrate* separated from ethanol as pale yellow needles, m. p. 107—108° (Found: C, 46·1; H, 3·8. $C_8H_{11}ON,C_6H_3O_7N_3$ requires C, 45·9; H, 3·8%).

5-Ethyl-2-methyl-4-nitropyridine N-Oxide (with R. M. Anderson).—A solution of the above oxide (52 g.) in concentrated sulphuric acid (98 ml.) was added dropwise to a stirred mixture of concentrated sulphuric acid (156 ml.) and concentrated nitric acid (175 ml.; *d* 1·42) at room temperature. The mixture was heated at 90—100° for 3 hr., cooled, and added dropwise to stirred concentrated aqueous ammonia and ice. The *nitro-compound* (48 g.) was collected, washed with a little ice-cold water, and recrystallised from acetone in pale yellow needles, m. p. 80° (Found: C, 52·8; H, 5·7. $C_8H_{10}O_3N_2$ requires C, 52·75; H, 5·5%).

4-Bromo-5-ethyl-2-methylpyridine (with R. M. Anderson).—Phosphorus tribromide (50 ml.) was added dropwise, with stirring, to a solution of the above nitro-compound (10 g.) in anhydrous benzene (50 ml.), and the mixture was heated under reflux in an oil-bath (125—140°), with stirring, for 7 hr. The cooled mixture was poured with stirring on ice, basified with 10% sodium hydroxide solution, and extracted with chloroform. Distillation of the dried (Na_2SO_4) extract gave the *bromopyridine* (6·6 g.), b. p. 105—110°/20 mm. (Found: C, 47·8; H, 4·8. $C_8H_{10}NBr$ requires C, 48·0; H, 5·0%). The *picrate* separated from ethanol in needles, m. p. 141—142° (decomp.) (Found: C, 39·5; H, 3·2. $C_8H_{10}NBr,C_6H_3O_7N_3$ requires C, 39·2; H, 3·0%). The *methiodide* crystallised from acetone–ether in prisms, m. p. 167—169° (Found: C, 31·8; H, 4·2. $C_8H_{10}NBr,CH_3I$ requires C, 31·6; H, 3·8%).

Ethyl 5-Ethyl-2-methylpyridine-4-carboxylate (with R. M. Anderson).—A solution of the bromo-compound (28 g.) in ethanol (120 ml.) was added to cuprous cyanide (20 g.), dissolved in water (180 ml.) containing potassium cyanide (46 g.), and the mixture was heated in an autoclave at 180—200° for 40 hr. The solution was adjusted to pH 4 with concentrated hydrochloric acid, and the precipitated cuprous cyanide was removed. The filtrate was evaporated to dryness under reduced pressure and the last traces of water were removed by evaporation to dryness three times with absolute alcohol. A mixture of the solid residue and absolute alcohol (100 ml.) was saturated with dry hydrogen chloride, kept overnight, then refluxed for 4 hr., and the alcohol was removed under reduced pressure. The residue was basified with saturated sodium carbonate solution and extracted with ether. Distillation of the dried (Na_2SO_4) extract gave the *ester* (12·5 g.), b. p. 112—115°/2 mm. (Found: C, 68·2; H, 8·0. $C_{11}H_{15}O_2N$ requires C, 68·4; H, 7·8%). The *picrate* separated from ethanol in needles, m. p. 129—130° (Found: C, 48·6; H, 4·5. $C_{11}H_{15}O_2N,C_6H_3O_7N_3$ requires C, 48·3; H, 4·3%).

[*Added, February 3rd*, 1956.—Berson and Cohen (*J. Org. Chem.*, 1955, **20**, 1461) have prepared methyl 5-ethyl-2-methylpyridine-4-carboxylate from 5-ethyl-2-methyl-4-nitropyridine *N*-oxide by a different method, involving five stages.]

5-Ethyl-2-methylpyridine-4-carboxylic Acid.—The above ester (0·8 g.) was refluxed with 20% potassium hydroxide solution (5 ml.) for 1½ hr. The solution was adjusted to pH 4 with dilute hydrochloric acid and extracted for 30 hr. continuously with ether. The ether was removed and the *acid* was sublimed at 140°/0·1 mm.; it had m. p. 226—228° (Found: C, 65·5; H, 6·9. $C_9H_{11}O_2N$ requires C, 65·5; H, 6·7%).

4-Acetyl-5-ethyl-2-methylpyridine.—To a suspension of potassium ethoxide (from potassium, 6·3 g.) in dry benzene were added the above ester (12·5 g.) and ethyl acetate (32 ml.). The mixture was refluxed on the water-bath for 12 hr. and water (140 ml.) was added. The solution was washed with ether to recover the uncondensed esters. Concentrated hydrochloric acid (280 ml.) was added to the aqueous solution, and the mixture was heated in the water-bath overnight. The solution was evaporated to dryness under reduced pressure, basified with saturated sodium carbonate solution, and extracted with ether. Distillation of the dried (Na_2SO_4) extract gave the *ketone* (7·3 g.), b. p. 114—118°/20 mm. (Found: C, 73·8; H, 8·3. $C_{10}H_{13}ON$ requires C, 73·6; H, 8·0%). The *picrate* crystallised from methanol in plates, m. p. 132—134° (Found: C, 49·2; H, 4·4. $C_{10}H_{13}ON,C_6H_3O_7N_3$ requires C, 49·0; H, 4·1%). The *oxime* crystallised from methanol in needles, m. p. 107° (Found: C, 67·3; H, 8·3. $C_{10}H_{14}ON_2$ requires C, 67·4; H, 7·9%).

4 : 5-Diethyl-2-methylpyridine.—A solution of the ketone (7·3 g.) in 17% hydrochloric acid (100 ml.) was added to freshly amalgamated zinc wool (25 g.). The mixture was refluxed for 10 hr. and concentrated hydrochloric acid (5 ml.) was added every 3 hr. The solution was decanted from the zinc, basified with excess of 40% sodium hydroxide solution, and extracted with ether. Distillation of the dried (Na_2SO_4) extract gave the base (4·3 g.), b. p. 88—92°/20 mm. (Found: C, 80·1; H, 10·4; N, 9·5. Calc. for $C_{10}H_{15}N$: C, 80·5; H, 10·1; N, 9·4%). The picrate crystallised from ethyl acetate in needles, m. p. 162—164° (Found: C, 50·7; H, 4·9.

Calc. for $C_{10}H_{15}N,C_6H_3O_7N_3$: C, 50·8; H, 4·8%). The *styphnate* crystallised from methanol in needles, m. p. 155—156° (Found: C, 48·7; H, 4·8. $C_{10}H_{15}N,C_6H_3O_8N_3$ requires C, 48·7; H, 4·6%). The residue from the above distillation gave *5-ethyl-4-1′-hydroxyethyl-2-methylpyridine*, b. p. 100—105°/0·1 mm. (Found: C, 72·8; H, 9·4. $C_{10}H_{15}ON$ requires C, 72·7; H, 9·1%), whose *picrate* crystallised from alcohol and had m. p. 137—139° (Found: C, 48·3; H, 4·5. $C_{10}H_{15}ON,C_6H_3O_7N_3$ requires C, 48·7; H, 4·6%).

The hydroxyethyl base (1·3 g.) was heated under reflux for 6 hr. with constant-boiling hydriodic acid (8·3 g.) and red phosphorus (0·4 g.). The mixture was diluted with water and filtered, and the filtrate basified with 20% sodium hydroxide solution and extracted with ether. Distillation of the dried (Na_2SO_4) extract gave 4 : 5-diethyl-2-methylpyridine, whose picrate was identical in m. p. and mixed m. p. with that described above.

4 : 5-*Diethyl-2-styrylpyridine*.—4 : 5-Diethyl-2-methylpyridine (4·3 g.), freshly distilled benzaldehyde (11 ml.), acetic anhydride (11 ml.), and xylene (12 ml.) were refluxed together for 70 hr. The solution was acidified (Congo-red) with 17% hydrochloric acid and steam-distilled to remove excess of benzaldehyde. After cooling, the mixture was basified with 20% sodium hydroxide solution and extracted with chloroform. Distillation of the dried (Na_2SO_4) extract gave (i) 4 : 5-diethyl-2-methylpyridine (1 g.) and (ii) the *product* (4·3 g.), b. p. 140—150°/0·1 mm. (Found: N, 5·5. $C_{17}H_{19}N$ requires N, 5·9%), whose picrate crystallised from acetone in needles, m. p. 241—243° (decomp.) (Found: C, 59·2; H, 4·8. Calc. for $C_{17}H_{19}N,C_6H_3O_7N_3$: C, 59·2; H, 4·7%). Kao and Robinson[11] gave m. p. 143—144°, but Sir Robert considers that this is probably a misprint in Dr. Kao's doctorate thesis.

4 : 5-*Diethylpyridine-2-carboxylic Acid* (III; R = Et).—A solution of the above styrylpyridine (2 g.) in acetone (25 ml.) was cooled in ice and stirred while finely powdered potassium permanganate (7 g.) was gradually added. The mixture was stirred for 1 hr. longer and then manganese dioxide was filtered off, washed with acetone, and extracted with hot water. The extract was acidified with dilute hydrochloric acid and cooled in ice, and the benzoic acid (1 g.) was extracted with ether. The aqueous solution was adjusted to pH 4 and extracted for 30 hr. continuously with ether. The ether was removed from the extract and the *product* (0·6 g.), m. p. 147—148°, crystallised from methanol (Found: C, 66·9; H, 7·6. $C_{10}H_{13}O_2N$ requires C, 67·0; H, 7·3%). Light absorption: $\lambda_{max.}$ 2680 and 2300 Å (log ε 3·61 and 3·90 respectively), $\lambda_{min.}$ 2520 Å (log ε 3·44). The acid of natural origin had m. p. 147—148° alone or mixed with our synthetic acid.

Decarboxylation of 4 : 5-*Diethylpyridine-2-carboxylic Acid*.—The synthetic acid (50 mg.), mixed with excess of dry, freshly precipitated copper powder, was gently heated with a free flame. The distillate gave a picrate which crystallised from ethanol in needles, m. p. 138—139°, not depressed on admixture with an authentic sample from 4 : 5-diethylpyridine (Found: C, 49·3; H, 4·5. Calc. for $C_9H_{13}N,C_6H_3O_7N_3$: C, 49·5; H, 4·4%).

Ethyl 4 : 5-*Diethylpyridine-2-carboxylate*.—The acid (0·6 g.), esterified with ethanol (10 ml.) and with dry hydrogen chloride at 0°, at room temperature overnight, and then at the b. p. for 2 hr., gave the *ester* (0·6 g.), b. p. 140—145°/3 mm. (Found: C, 69·9; H, 8·6. $C_{12}H_{17}O_2N$ requires C, 69·6; H, 8·2%), whose *picrate* (from ethanol) had m. p. 88—90° (Found: C, 49·6; H, 4·7. $C_{12}H_{17}O_2N,C_6H_3O_7N_3$ requires C, 49·5; H, 4·6%).

2-*Carbamoyl*-4 : 5-*diethylpyridine*.—The crude ester (0·5 g.) was kept with concentrated ammonia solution (5 ml.) for 48 hr. at room temperature and stirred for 2 hr. The *amide* (0·4 g.) was filtered off and sublimed at 100—120°/0·1 mm.; it had m. p. 177—178° (Found: C, 67·6; H, 7·8. $C_{10}H_{14}ON_2$ requires C, 67·4; H, 7·9%).

2-*Cyano*-4 : 5-*diethylpyridine*.—The amide (0·4 g.) and phosphorus oxychloride (1 ml.) were refluxed for 2 hr. The excess of oxychloride was removed under reduced pressure, and the residue basified with saturated sodium carbonate solution and extracted with chloroform. Distillation of the dried (Na_2SO_4) extract gave the *cyanopyridine* (0·2 g.), b. p. 150—160°/20 mm. (Found: C, 75·2; H, 7·6. $C_{10}H_{12}N_2$ requires C, 75·0; H, 7·5%).

2-*Butyryl*-4 : 5-*diethylpyridine*.—A solution of the above nitrile (1·3 g.) in anhydrous ether (75 ml.) was added gradually with stirring at room temperature to a solution of *n*-propylmagnesium bromide (from magnesium, 0·6 g., and *n*-propyl bromide, 2·7 g., in anhydrous ether, 15 ml.). The mixture was refluxed for 3 hr., and then decomposed by saturated ammonium chloride solution (30 ml.) and concentrated hydrochloric acid (5 ml.). The solution was basified with 10% sodium hydroxide solution, and extracted with ether. Distillation of the dried (Na_2SO_4) extract gave the *ketone* (1·2 g.), b. p. 142—146°/3 mm. (Found: C, 76·6; H, 9·1. $C_{12}H_{19}ON$ requires C, 76·1; H, 9·3%). The *picrate* (from ethanol) had m. p. 97—98° (Found: C, 53·1; H, 5·4. $C_{12}H_{19}ON,C_6H_3O_7N_3$ requires C, 52·6; H, 5·1%). The *phenylhydrazone*

picrate crystallised from ethanol as orange needles, m. p. 211—212° (Found: C, 57·1; H, 5·3. $C_{19}H_{25}N_3,C_6H_3O_7N_3$ requires C, 57·25; H, 5·3%). The red p-*methoxyphenylhydrazone picrate* (from ethanol) had m. p. 160—161° (Found: C, 56·3; H, 5·6. $C_{26}H_{30}O_8N_6$ requires C, 56·3; H, 5·4%).

2-(4 : 5-*Diethyl*-2-*pyridyl*)-3-*ethylindole* (I; R = Et).—The above ketone (0·334 g.) and freshly distilled phenylhydrazine (0·18 g.) were heated together in a vacuum on the steam-bath for 2 hr. The residual mass was dissolved in absolute alcohol (20 ml.), cooled in ice, and saturated with dry hydrogen chloride. The solution was kept at room temperature for 1 hr. and refluxed for 2 hr.; ammonium chloride separated, and, after cooling, the hydrochloride crystallised as yellow needles. The mixture was evaporated to dryness under reduced pressure, water was added, and the mixture was basified with saturated sodium carbonate solution and extracted with ether. Distillation of the dried (Na_2SO_4) extract gave the indole (0·3 g.) as a pale yellow, viscous oil, b. p. (bath-temp.) 200—210°/0·4 mm., which solidified on trituration with ether and crystallised from methanol as pure white prisms, m. p. 110—111°, not depressed on admixture with alstyrine obtained by degradation of corynantheine and alstonine (Found: C, 81·8; H, 7·9 Calc. for $C_{19}H_{22}N_2$: C, 82·0; H, 7·9%). Light absorption: $\lambda_{max.}$ 3250 Å (log ε 4·36), $\lambda_{min.}$ 2740 Å (log ε 3·63). The *picrate* (from ethanol), m. p. 218—221°, did not depress the m. p. of the picrate of the compound of natural origin (Found: C, 58·9; H, 5·2. $C_{19}H_{22}N_2,C_6H_3O_7N_3$ requires C, 59·1; H, 4·9%). The yellow *hydrochloride* (from ethyl acetate) softened at 190° and melted completely at 203° (Found: C, 72·2; H, 7·7. $C_{19}H_{22}N_2,HCl$ requires C, 72·5; H, 7·3%).

2-*Carbamoyl*-5-*ethylpyridine*.—As in the above synthesis of 2-carbamoyl-4 : 5-diethylpyridine, a mixture of ethyl 5-ethylpyridine-2-carboxylate [1] (4 g.) and concentrated ammonia solution (40 ml.) gave the *amide* (3·0 g.), which crystallised from water as needles, m. p. 147—148°, and sublimed at 120°/0·05 mm. (Found: C, 64·25; H, 6·9. $C_8H_{10}ON_2$ requires C, 64·0; H, 6·7%).

2-*Cyano*-5-*ethylpyridine*.—As above, this amide (3 g.) and phosphorus oxychloride (6 g.) gave the *nitrile* (1·7 g.), b. p. 132°/20 mm. (Found: C, 72·4; H, 6·2. $C_8H_8N_2$ requires C, 72·7; H 6·1%).

2-*Butyryl*-5-*ethylpyridine*.—As in the synthesis of 2-butyryl-4 : 5-diethylpyridine, this nitrile (1·7 g.) in ether (50 ml.) and *n*-propylmagnesium bromide [from magnesium (0·5 g.) and *n*-propyl bromide (2·8 g.) in ether (15 ml.)] yielded the ketone (1·3 g.), b. p. 120—125°/20 mm. (Found: C, 74·4; H, 9·2; N, 7·6. Calc. for $C_{11}H_{15}ON$: C, 74·6; H, 8·5; N, 7·9%). The picrate (from ethanol) had m. p. 118—120° (Found: C, 49·8; H, 4·7. Calc. for $C_{11}H_{15}ON,C_6H_3O_7N_3$: C, 50·2; H, 4·4%). The phenylhydrazone picrate separated from ethanol as orange needles, m. p. 178° (Found: C, 55·5; H, 5·0. Calc. for $C_{17}H_{21}N_3,C_6H_3O_7N_3$: C, 55·6; H, 4·7%). The p-*methoxyphenylhydrazone picrate* separated from ethanol as orange plates, m. p. 176—177° (Found: C, 54·7; H, 4·9. $C_{18}H_{23}ON_3,C_6H_3O_7N_3$ requires C, 54·8; H, 4·9%).

3-*Ethyl*-2-(5-*ethyl*-2-*pyridyl*)-5-*methoxyindole* (IV; R = H).—The above ketone (1·2 g.) and *p*-methoxyphenylhydrazine (from *p*-methoxyphenylhydrazine hydrochloride, 1·3 g.) were heated in a steam-bath in a vacuum for 2 hr. The *indole*, which was obtained as in the case of 2-(4 : 5-diethyl-2-pyridyl)-3-ethylindole, distilled as a yellow viscous oil, b. p. (bath-temp.) 200—220°/0·4 mm., and solidified on trituration with light petroleum (b. p. 60—80°), then crystallised therefrom as yellow prisms, m. p. 111—112° (Found: C, 76·9; H, 7·0. $C_{18}H_{20}ON_2$ requires C, 77·1; H, 7·2%). Light absorption: $\lambda_{max.}$ 3320 Å (log ε 4·49), $\lambda_{min.}$ 2720 Å (log ε 3·76). The *picrate* (from ethanol) had m. p. 201—203° (Found: C, 56·6; H, 4·5. $C_{18}H_{20}ON_2,C_6H_3O_7N_3$ requires C, 56·6; H, 4·5%).

2-(4 : 5-*Diethyl*-2-*pyridyl*)-3-*ethyl*-5-*methoxyindole* (IV; R = Et).—As above, 2-butyryl-4 : 5-diethylpyridine and *p*-methoxyphenylhydrazine gave the *indole*, b. p. (bath-temp.) 200—220°/0·1 mm., which separated from light petroleum (b. p. 60—80°) as pale yellow needles, m. p. 118° (Found: C, 77·7; H, 7·9. $C_{20}H_{24}ON_2$ requires C, 77·9; H, 7·8%). Light absorption: $\lambda_{max.}$ 3290 Å (log ε 4·43), $\lambda_{min.}$ 2730 Å (log ε 3·67). A mixture of the base with 3-ethyl-2-(5-ethyl-2-pyridyl)-5-methoxyindole had m. p. 85—95°. The *picrate* (from ethanol) had m. p. 225° (decomp.) (Found: C, 57·6; H, 4·9. $C_{20}H_{24}ON_2,C_6H_3O_7N_3$ requires C, 58·1; H, 5·0%).

Thanks are offered to Professor P. Karrer for samples of alstyrine and 3 : 4-diethylpyridine picrate, to Dr. T. M. Sharp for a sample of alstyrine, to Professor M.-M. Janot for one of 4 : 5-diethylpyridine-2-carboxylic acid, to Mr. R. E. Dodd for the measurement of the infrared spectra, to the Department of Scientific and Industrial Research for a maintenance grant (to T. B. L.), and to Professor G. R. Clemo, F.R.S., for his interest.

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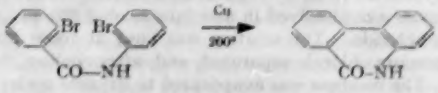
154. *2-Bromo-4- and -5-methylbenzoic Acid and Some Related Compounds.*

By M. S. Gibson.

It was desired to prepared phenanthridones by the general method :



As intermediates, 2 : 2′-dibromo-4-methylbenzanilide and 2 : 2′-dibromo-5-methylbenzanilide have been prepared, but under the conditions of the Ullmann reaction gave only amorphous products. Whilst the main project was unsuccessful, the preparation of the intermediate acids has indicated a number of discrepancies in the literature.

Experimental.—Some analyses are by Mr. F. C. Hall.

2-Bromo-4-methylbenzoic acid. A solution of 2-bromo-4-methylbenzonitrile [1] (10 g.) and potassium hydroxide (4 g.) in aqueous ethanol was boiled for 6 hr. Ethanol was removed *in vacuo*, and the residual solution decolorised with charcoal. On cooling, the solution deposited needles, m. p. 171—173°. Acidification of the filtrate precipitated 2-bromo-4-methylbenzoic acid, which crystallised from aqueous ethanol in needles, m. p. 141—142°. Claus and Kunath [2] give m. p. 140°.

Crystallisation of the solid, m. p. 171—173°, from a large volume of water afforded needles of 2-bromo-4-methylbenzamide, m. p. and mixed m. p. 175—176° (Found : C, 45·1; H, 3·8; N, 6·7; Br, 37·1. Calc. for C_8H_8ONBr : C, 44·9; H, 3·7; N, 6·5; Br, 37·4%); Claus and Kunath,[2] however, record the m. p. 137°.

2-Bromo-N-o-bromophenyl-4-methylbenzamide, prepared from *o*-bromoaniline by the Schotten–Baumann method, crystallised from ethanol in needles, m. p. 145—146° (Found : C, 45·9; H, 3·0; N, 3·9. $C_{14}H_{11}ONBr_2$ requires C, 45·5; H, 3·0; N, 3·8%). An attempt to convert the anilide into 6-methylphenanthridone by copper powder at 200—220° yielded only amorphous material.

2-Bromo-5-methylaniline.—The following method of reduction of 2-bromo-5-methylnitrobenzene was more convenient than that of Borsche and Scriba.[3] Iron filings (100 g.) were added during 20 min. to a boiling solution of the nitro-compound (120 g.) in ethanol (280 c.c.) and concentrated hydrochloric acid (6 c.c.) with vigorous shaking. After 2 hours' boiling, sodium hydroxide was added, the mixture distilled in steam, and the distillate discarded until it became turbid. The amine (90 g.) which then distilled was isolated by means of ether and converted into the nitrile without purification. The acetyl derivative formed needles (from aqueous ethanol), m. p. 123—124° (Found : C, 47·0; H, 4·1; N, 6·1; Br, 35·3. Calc. for $C_9H_{10}ONBr$: C, 47·4; H, 4·4; N, 6·1; Br, 35·1%); for this compound, Nevile and Winther [4] give m. p. 113·7—114·6°.

2-Bromo-5-methylbenzoic acid. A solution of 2-bromo-5-methylbenzonitrile [3] (10 g.) and potassium hydroxide (4 g.) in aqueous ethanol was boiled for 6 hr. The acid was isolated in the normal manner, and after crystallisation from water, formed needles, m. p. 137—138° (Found : C, 44·9; H, 3·6. Calc. for $C_8H_7O_2Br$: C, 44·7; H, 3·3%) (Claus [5] gives m. p. 154—155°; Borsche and Herbert [6] record m. p. 135°; the latter workers hydrolysed the nitrile by acid but alkaline hydrolysis has been found to give a cleaner product).

2-Bromo-N-o-bromophenyl-5-methylbenzamide separated from ethanol in needles, m. p. 118—119° (Found : C, 45·6; H, 3·1; N, 3·9; Br, 43·1. $C_{14}H_{11}ONBr_2$ requires C, 45·5; H, 3·0; N, 3·8; Br, 43·4%). In an Ullmann reaction, this anilide gave an amorphous product.

4-Bromoisophthalic acid. Potassium permanganate (1·6 g.) in water (30 c.c.) was slowly added to a boiling solution of 2-bromo-5-methylbenzoic acid (1 g.) in dilute sodium hydroxide solution. The mixture was boiled for 3 hr., cooled, and saturated with sulphur dioxide. Crystallisation of the precipitated acid from aqueous ethanol afforded needles, m. p. 303—304°

[1] Lindemann and Pabst, *Annalen*, 1928, **462**, 24.
[2] Claus and Kunath, *J. prakt. Chem.*, 1889, **39**, 485.
[3] Borsche and Scriba, *Annalen*, 1939, **541**, 283.
[4] Nevile and Winther, *Ber.*, 1880, **13**, 962.
[5] Claus, *J. prakt. Chem.*, 1892, **46**, 20.
[6] Borsche and Herbert, *Annalen*, 1941, **546**, 277.

(Found: C, 39·4; H, 2·1. Calc. for $C_8H_5O_4Br$: C, 39·2; H, 2·0%). For this acid, Claus [6] records m. p. 287°; Schöpff [7] reports m. p. 283°. 4-Bromo*iso*phthalic acid, prepared from *m*-xylene by bromination, followed by oxidation with potassium permanganate,[7] and twice crystallised from ethanol in which it is moderately soluble, afforded 4-bromo*iso*phthalic acid as needles, m. p. 302—303°. A mixed m. p. with the above-mentioned specimen showed no depression.

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DYSON PERRINS LABORATORY, OXFORD. [*Received, August 15th*, 1955.]

[7] Schöpff, *Ber.*, 1891, **24**, 3771.

155. *The Isolation of Octadec-8 : 10 : 12-trienoic Acid from Marigold-seed Oil.*

By JOHN MCLEAN and A. H. CLARK.

EXTRACTION of the crushed seeds of Scots Marigold (*Calendula officinalis*) with light petroleum gives a relatively high yield (24%) of oil, the ultraviolet absorption spectrum of which suggests that about 56% of it is a conjugated trienoic acid (or ester). Attempts directly to isolate the trienoic acid were unsuccessful because of the ease with which it autoxidised. When refluxed with alcoholic potassium hydroxide in the presence of traces of sulphur, the oil gives an acid fraction (approx. 30%) which readily yields a crystalline acid, $C_{18}H_{30}O_2$, m. p. 77—78°, identified as octadec-8 : 10 : 12-trienoic acid as described below. Hydrogenation of the acid over Raney nickel gives stearic acid in high yield. The presence of three conjugated double bonds is established by the ultraviolet spectrum which shows maxima at 2580, 2680, and 2800 Å (ε 44,100, 59,100, 45,600), in this respect resembling the isomeric β-elæostearic acid [1] (maxima at 2590, 2680, and 2800 Å). Oxidation of the acid with potassium permanganate gives a mixture from which hexanoic acid (as its *p*-bromophenacyl ester) and suberic acid were isolated.

Octadec-8 : 10 : 12-trienoic acid, m. p. 77—78°, readily forms an adduct with maleic anhydride, the infrared absorption spectrum of which includes bands at 958 and 687 cm.$^{-1}$, the former attributed to an exocyclic *trans*-disubstituted ethylenic bond and the latter to the *cis*-disubstituted double bond in a hydroaromatic ring. The ease with which maleic anhydride forms an adduct with the trienoic acid proves, in our opinion, that the conjugated double bonds directly involved are orientated *trans-trans*, thus leading to the view that the octadec-8 : 10 : 12-trienoic acid is the all-*trans*-isomer. In this respect, it is related to β-elæostearic acid (all-*trans*-octadec-9 : 11 : 13-trienoic acid).[2] α-Elæostearic acid (the *cis-trans-trans*-isomer) is converted into its β-isomer (all-*trans*) by treatment with alkali in the presence of sulphur [3] and we assume that a similar change has occurred during the isolation of all-*trans*-octadec-8 : 10 : 12-trienoic acid from marigold-seed oil.

Experimental.—Ultraviolet spectra were measured in EtOH and infrared spectra were determined in CS_2 solutions.

Marigold-seed oil. Marigold seed (2 lb.) was extracted continuously with light petroleum (b. p. 60—80°) to remove the outer wax coating (1·5 g.). The seed was crushed and again extracted continuously with light petroleum. Removal of the solvent gave a pale green oil (219 g.), having absorption: max. at 2620, 2710, and 2820 Å ($E^{1\%}_{1\,cm.}$ 1000 at 2710 Å).

all-trans-*Octadec*-8 : 10 : 12-*trienoic acid.* A mixture of marigold-seed oil (34 g.), potassium hydroxide (13·6 g.), ethanol (140 c.c.), and sulphur (0·7 g.) was refluxed for 1½ hr. The alcohol was removed by distillation, water being added continuously to avoid concentration of alkali, and the non-saponifiable matter extracted with ether (500 c.c.). The aqueous phase was

[1] Ahlers and Gunstone, *Chem. and Ind.*, 1954, 1291.
[2] Paschke, Tolberg, and Wheeler, *J. Amer. Oil Chemists' Soc.*, 1953, **30**, 97; Bickford, du Pré, Mack, and O'Connor, *ibid.*, p. 376.
[3] Thomas and Thomson, *J. Amer. Chem. Soc.*, 1934, **56**, 898.

acidified with hot 2N-sulphuric acid (250 c.c.), and the precipitated acids were washed with hot water and finally with ice water. Four crystallisations from ethanol (90%) and one from light petroleum gave all-trans-*octadec*-8 : 10 : 12-*trienoic acid* (1·7 g.) as plates, m. p. 77—78° (Found : C, 77·5; H, 10·9. $C_{18}H_{30}O_2$ requires C, 77·65; H, 10·9%). Light absorption : Max. at 2580, 2680, 2800 Å (ε respectively 44,100, 59,100, and 45,600). The *maleic anhydride adduct*, prepared by refluxing the acid with excess of maleic anhydride in toluene for 1 hr., separated as rosettes, m. p. 71°, from light petroleum (Found : C, 70·4; H, 8·7. $C_{22}H_{32}O_5$ requires C, 70·2; H, 8·6%).

Hydrogenation. Octadec-8 : 10 : 12-trienoic acid (0·3 g.) in ethyl acetate was shaken with hydrogen over Raney nickel. Isolation in the usual manner followed by crystallisation from light petroleum gave stearic acid (0·2 g.), m. p. and mixed m. p. 69—70°.

Oxidation. The trienoic acid (5 g.) in water (1540 c.c.) containing potassium hydroxide (1 g.) was treated with 4·8% aqueous potassium permanganate (580 c.c.) during 2 hr. with stirring. The mixture was kept at room temperature for 48 hr. and then treated with sulphur dioxide. The solution was distilled down to 50 c.c., the distillate being collected in 5% aqueous sodium hydroxide (50 c.c.). Acidification of the distillate and extraction with ether gave hexanoic acid, identified as the *p*-bromophenacyl ester, m. p. and mixed m. p. 72° (Found : C, 53·5; H, 5·8. Calc. for $C_{14}H_{17}O_3Br$: C, 53·7; H, 5·5%). The aqueous residue in the distillation flask deposited crude suberic acid (2·8 g.) on cooling. Repeated crystallisation from benzene gave the pure acid, m. p. and mixed m. p. 138—139° (*p*-bromophenacyl ester, m. p. 145°, phenacyl ester, m. p. and mixed m. p. 103°).

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THE ROYAL TECHNICAL COLLEGE, GLASGOW. [*Received, September 8th*, 1955.]

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156. *The Stability of* H_2^+ *and* OH^+ *in Aqueous Solutions.*

By C. A. COULSON.

SINCE the original suggestion by Weiss [1] it has become recognised that the positive ion H_2^+ may act as a centre capable of co-ordinating water molecules in aqueous solution, and in recent months many applications of this concept have been made.[2,3] It has also been suggested by various authors [4] that possibly the positive ion OH^+ might possess a similar stability in aqueous solution. This suggestion is made a little more plausible by the fact that both H_2^+ and OH^+ are found in the mass spectrograph. It is true that in the conventional heterolytic reaction theory of hydroxylation we are more accustomed to the anion OH^- than the cation OH^+. But the possible biological, radiochemical, and pure chemical interests of this problem seem to warrant a discussion of the comparative efficiencies of H_2^+ and OH^+ in the co-ordination of a shell of water molecules. The purpose of the present note is to suggest why, although a final decision cannot yet be reached, it seems unlikely that OH^+ would behave analogously to H_2^+.

First, we may enquire about possible modes of formation of H_2^+ and OH^+ in aqueous solutions. It is reasonable to suppose that the ions most frequently formed in water by the passage of an ionising particle are H_2O^+ and H_2O^-. It is true that incident neutrons may eject protons from H_2O, but each of these recoil protons will itself ionise a large number of other water molecules before coming to rest. With fast neutrons the number of protons (and therefore residual OH radicals and ions) produced in this primary fashion may only be of the order of 10^{-4} times the number of ions subsequently produced by these recoil protons and associated secondary electrons. We therefore restrict our attention to the primary species H_2O^+ and H_2O^-. Now the positive ion OH^+ could hardly be formed directly from H_2O^-. So far as OH^+ is concerned, therefore, we need only consider H_2O^+.

[1] Weiss, *Nature*, 1950, **165**, 728.
[2] *E.g.* : Rigg, Stein, and Weiss, *Proc. Roy. Soc.*, 1952, *A*, **211**, 375; Rigg and Weiss, *J. Chem. Phys.*, 1952, **20**, 1194; *J.*, 1952, 4198; Hart, *Radiation Res.*, 1954, **1**, 53; Allen, *ibid.*, p. 85; Hart, *J. Amer. Chem. Soc.*, 1954, **76**, 4198; Sworski, *ibid.*, p. 4687.
[3] Dewhurst, Samuel, and Magee, *Radiation Res.*, 1954, **1**, 60.
[4] Cf. ref. 3, p. 67.

In the presence of water this radical would presumably break up in either of the following ways, which are almost equally energetic in the gas phase :

$$H_2O^+ \longrightarrow OH + H^+$$
$$H_2O^+ \longrightarrow OH^+ + H$$

(There is, however, a possibility that H_2O^+ may itself have a certain stability in aqueous solutions.) If OH^+ is created in this process, there is the possibility (see below) of its disappearance in an electron-transfer reaction

$$OH^+ + H_2O \longrightarrow OH + H_2O^+$$

or alternatively in the reaction

$$OH^+ + H_2O \longrightarrow H_2O^+ + O$$

leading to a strongly hydrated proton and possible formation of oxygen gas, O_2, for whose existence there is experimental evidence. On the basis of these considerations alone, therefore, it is not very likely that OH^+ would appear in an aqueous system.

For H_2^+, the situation is rather different. There appears no possibility of primary formation of H_2^+ (except perhaps $H_2O^+ \longrightarrow H_2^+ + O$) and it is presumed that H_2^+ in aqueous system is formed by the interaction :

$$H + H^+ \rightleftharpoons H_2^+$$

which could also be written (cf. Weiss [1]) as :

$$H + H_2O^+ \rightleftharpoons H_4O^+$$

so that this species is in continuous equilibrium with the hydrogen ions in the solution. There is no difficulty, therefore, in explaining the origin of H_2^+.

Next, let us compare the ions H_2^+ and OH^+ as regards their power of co-ordinating water molecules. Co-ordination of H_2O molecules around a positive ion is largely due to attraction, by the electrostatic field of the ion, of the negative end of the H_2O molecules—in this case the region of predominantly negative charge surrounding the oxygen atoms. Now at sufficiently large distances this electrostatic field will be effectively the same for both OH^+ and H_2^+, since it depends simply on the total positive charge. But at closer distances, which are necessary if full use is to be made of this electrostatic field, these two ions will behave quite differently towards approaching water molecules. There appear to be at least four ways in which this difference may be expected from our present knowledge of the electronic structure of the ions themselves.

(1) The H_2^+ molecule has only one electron, and this is almost entirely found in regions between the nuclei, hardly ever on the further sides. The accurate curve [5] in Fig. 1 shows the density distribution along the central axis of the molecule. Thus from many points of view the H_2^+ ion will behave as if it were a single bare proton, split into two halves, separated by about 1 Å. There is no effective screening of the nuclei by the one electron that does exist, and water molecules can therefore approach quite close to the two nuclei. This may be seen very clearly if we recall that, with a reasonable definition of the volume of a molecule, the volume of H_2^+ is considerably less even than that of atomic hydrogen. The charge-cloud pattern of H_2^+ is shown rather schematically in Fig. 2.

(2) The ion OH^+, on the other hand, has acquired its positive charge by losing one of the non-bonding electrons of the oxygen atom. There remain two electrons in the bond, so that, as comparisons of accurate electron-density diagrams for H_2^+ and H_2 show, there is now a considerable electronic density on the remote side of the hydrogen nucleus; thus an approaching water molecule would have little tendency to co-ordinate at this end of the ion. But if such a molecule came near the other end it would not be able to get very close before experiencing repulsions due to overlapping of its charge cloud with that of the oxygen atom.

[5] Burrau, *Kgl. danske Videnskab. Selskab, Mat.-fys. Medd.*, 1927, **7**, 1.

Thus we may argue that the effective radius of the oxygen atom in OH^+ is greater than that of the hydrogen atoms in H_2^+, and the co-ordinating power correspondingly less. A schematic charge-cloud pattern is shown in Fig. 3.

(3) The situation just described is actually rendered a little more unfavourable to co-ordination because, on account of the resultant positive charge near the oxygen nucleus, the electrons of the O–H bond will be drawn in a little towards the oxygen atom, and will partly neutralise this charge.

(4) Our last point arises out of a consideration of the ionisation potentials of H_2O and

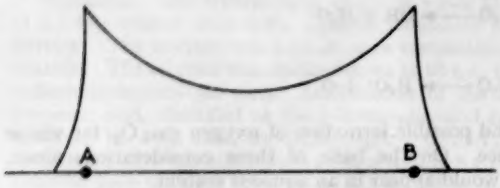
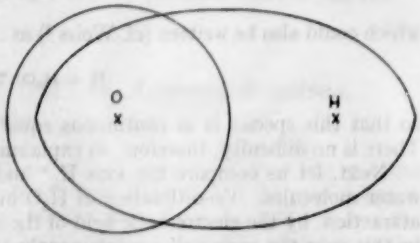


FIG. 1. *Charge-cloud along the axis of* H_2^+ *(after Burrau* [5]*).*

FIG. 2. *Charge-cloud for* H_2^+. *Almost all the charge lies within the contour shown. This contour approaches very closely to the nuclei* A *and* B *on the sides remote from each other. There is symmetry around the axis* A–B.

FIG. 3. *Charge-cloud for* OH^+. *Almost all the bonding charge lies in the ellipsoidal contour; almost all non-bonding charge lies within the spherical contour. There is symmetry around the axis* O–H.



OH. These are 12·6 and 13·6 —13·8 ev respectively,[6] showing that it is easier to remove an electron (usually a non-bonding electron) from H_2O than OH. As a result the reaction

$$H_2O + OH^+ \longrightarrow H_2O^+ + OH$$

in the vapour phase will go in the direction shown by the arrow. Consequently one may expect that co-ordination of water molecules around an OH^+ ion would soon transform that ion into a neutral radical OH, with the formation of an H_2O^+ ion instead.

None of the discussion just given makes it absolutely certain that OH^+ does not exist in a state co-ordinated with water molecules. But, taken collectively, it suggests that such stability as a hydrated OH^+ might possess in this way is distinctly less than that of a hydrated H_2^+.

The writer acknowledges the benefit of discussions with Dr. J. Weiss, who brought the problem to his attention, and pointed out the need for a clarification of the issues involved.

MATHEMATICAL INSTITUTE, OXFORD. [*Received, June 6th*, 1955.]

[6] Tsuchiya, *J. Chem. Phys.*, **1954**, **22**, 1784; Price and Sugden, *Trans. Faraday Soc.*, **1948**, **44**, 108; Robertson, *ibid.*, 1952, **48**, 228.

157. *The Preparation and Properties of Some Plutonium Compounds. Part III.* X-Ray Diffraction Studies of Plutonium Hydride.*

By B. J. McDonald and J. B. Fardon.

As far as is known to us there are no published data on the crystal structure of plutonium hydrides. Reference is made to hydrides PuH_2 and PuH_3 by Cunningham,[1] the formulæ being deduced by gas-displacement and dissociation-pressure methods. It is also stated that the dihydride forms a solid solution with the trihydride.

The plutonium–hydrogen system has recently been investigated [2] and in conjunction with this work we have examined powder diffraction patterns of the resultant plutonium hydride.

All the samples examined showed the same powder pattern. This consisted of a strong face-centred cubic phase with lattice parameter 5·34 Å and a very weak system which was probably hexagonal with parameters a 3·78, c 6·76 Å.

The chemical formula [2] of these samples, $PuH_{2\cdot7}$, admits the following interpretations of the observed diffraction patterns: (*a*) the cubic and the hexagonal phase represent two plutonium hydrides, which would require 70% of PuH_3 and 30% of PuH_2. This is not considered likely because the hexagonal pattern observed is too weak and represents only about 5—10% of the whole. (*b*) The strong cubic phase represents a solid solution of PuH_3 in PuH_2 as suggested by Bakes and Johns,[3] and the hexagonal phase is an impurity; this cannot be verified since no reference data on PuH_2 and PuH_3 are available. (*c*) The strong cubic phase represents a solid solution of hydrogen in PuH_2, the additional hydrogen atoms occupying some of the interstitial positions and the hexagonal phase being either an impurity or possibly PuH_3.

The hexagonal phase does not correspond to any of the known allotropes of plutonium or to any oxide of plutonium, data for all these having been examined since they are the most likely impurities.

It is suggested, therefore, that the cubic phase is a solid solution of either PuH_3 or hydrogen in PuH_2 and that the hexagonal phase may be another plutonium hydride, possibly PuH_3.

Experimental.—Preparation of the plutonium hydride is described by Brown *et al.*,[2] special precautions being taken to prevent contamination or oxidation of the product, which was a very finely divided black powder. It was photographed after binding with Canada balsam, in a 19 cm. camera (to be described elsewhere).

None of the samples photographed gave a sharp diffraction pattern, showing that the particle size was less than 1 μ (uranium hydride also shows this effect). The consequent diffuseness of the high-angle lines prevented very accurate measurements of the lattice parameter. Tables 1 and 2 give the data obtained. The intensities were estimated visually, relatively to the strongest line in the complete pattern (d 3·08 Å).

Table 1. *Cubic phase.*

Line no.	d (Å)	*hkl*	Relative intensity	Line no.	d (Å)	*hkl*	Relative intensity	Line no.	d (Å)	*hkl*	Relative intensity
1	3·08	111	100	6	1·33	400	10	11	0·9435	440	20
2	2·67	200	40	7	1·23	331	50	12	0·9028	531	50
3	1·89	220	70	8	1·19	420	40	13	0·8897	600, 442	50
4	1·61	311	80	9	1·090	422	50	14	0·8430	620	30
5	1·54	222	30	10	1·027	333, 511	50				

* Part II, *J.*, 1955, 4196.

[1] Cunningham, "The Actinide Elements," McGraw-Hill, New York, 1954.
[2] Brown, Ockenden, and Welch, *J.*, 1955, 3932.
[3] Baker and Johns, reported by Johns, L.A.D.C. 277, Sept. 1944; M.D.D.C. 717, Feb. 1947, declassified Feb. 1947.

TABLE 2. *Hexagonal phase.*

Line no.	*d* (Å)	*hkl*	Relative intensity	Line no.	*d* (Å)	*hkl*	Relative intensity
1	3·38	002	5	4	2·36	102	5
2	3·27	100	5	5	1·85	103	10
3	2·94	101	20	6	1·64	112	5

The lattice parameter of the cubic phase was calculated by using the Nelson–Riley extrapolation [4] on results from several different samples. The results (5·340 Å for 3 samples, 5·341 and 5·342 for one each) give a calculated density 10·6.

Some difficulty was experienced in indexing the hexagonal phase owing to the very faint lines and consequent uncertainty in the *d* values, particularly the first two. It is thought that the indices given are correct. They were obtained by using Bunn charts (cf. above).

The samples of plutonium hydride used in this work were prepared by Mrs. H. M. Ockenden and we acknowledge helpful discussions with Mrs. Ockenden and G. A. Welch on many points in this work. Thanks are offered to the Managing Director of this Group for permission to publish this paper.

U.K. ATOMIC ENERGY AUTHORITY (INDUSTRIAL GROUP),
WINDSCALE WORKS, CUMBERLAND.

[*Received, June 10th*, 1955.]

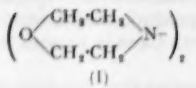
[4] Nelson and Riley, *Proc. Phys. Soc.*, 1945, **57**, 160.

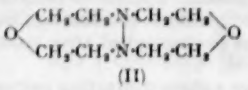
158. *The Reaction of Di-(2-chloroethyl) Ether with Hydrazine.*

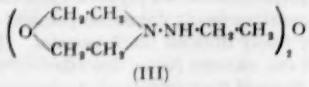
By W. V. FARRAR.

ACCORDING to a patent [1] di-(2-hydrazinoethyl) ether (not characterised) can be prepared by the reaction of di-(2-chloroethyl) ether with excess of hydrazine in ethanol. This could not be confirmed; the only product isolated was 4-aminomorpholine.[2]

When the reaction was conducted in water, the main product was still 4-aminomorpholine, but 5—10% of di-4-morpholinyl (I) was also isolated, together with minor quantities of another base (isolated as dipicrate) whose analysis corresponded to di-(2-4′-morpholinylaminoethyl) ether (III). Di-4-morpholinyl has m. p. 103°: the unlikely


(I)


(II)


(III)

formula (II) is excluded by an alternative synthesis from 4-aminomorpholine and di-(2-chloroethyl) ether. It is probably identical with "polydehydromorpholine," m. p. 105—106° (corr.), which Henry and Dehn [3] obtained by the action of alkali on 4-chloromorpholine; the attempts of these authors to demonstrate the presence of an NH group are unconvincing; their α-naphthyl *iso*cyanate derivative is clearly not a chemical individual, and their supposed acetyl derivative is probably acetomorpholide.

Experimental.—Reaction in ethanol. Hydrazine hydrate (60 g.) and ethanol (200 c.c.) were refluxed, and di-(2-chloroethyl) ether (30 g.) added during 1 hr.; refluxing was continued for a further 1·5 hr. The product (2 layers) was distilled to small bulk, then taken up in water, and excess of hydrazine precipitated by the addition of sulphuric acid (98 g. of hydrazine sulphate recovered). The filtrate was evaporated to a syrup and stirred with cold ethanol, giving *4-aminomorpholine sulphate* (25 g.), plates (from aqueous ethanol), m. p. 242° (decomp.) (Found: N, 18·5. $C_4H_{10}ON_2,H_2SO_4$ requires N, 18·5%). The picrate was very soluble, but a *compound* was precipitated when hydrazine was present, consisting of 1 mol. each of 4-aminomorpholine, hydrazine hydrate, and picric acid: it formed bright yellow needles, m. p. 180—185° (decomp.),

[1] Dreyfus, B.P. 594, 453.
[2] Knorr and Browndson, *Ber.*, 1902, **35**, 4414.
[3] Henry and Dehn, *J. Amer. Chem. Soc.*, 1950, **72**, 2280.

from aqueous ethanol (Found: N, 25·85, 25·3. $C_4H_{10}ON_2 + N_2H_4O + C_6H_9O_7N_3$ requires N, 25·7%).

The ultimate mother-liquors from the sulphate crystallisation (above) were treated with benzaldehyde, giving a benzylidene derivative, m. p. 79—84°, which did not depress the m. p. of 4-benzylideneaminomorpholine (m. p. 88—89°). No appreciable amounts of any other hydrazine with unsubstituted amino-groups can therefore be present.

Reaction in water. Di-(2-chloroethyl) ether (100 g.), hydrazine sulphate (52 g.), sodium hydroxide (64 g.), and water (650 c.c.) were refluxed for 15 hr. The product was acidified, extracted with ether, basified with aqueous sodium hydroxide, and again extracted with ether. The latter extracts were dried (Na_2SO_4) and evaporated, leaving a sticky crystalline residue; washing with cold ether left *di-4-morpholinyl* (3—5 g.). Recrystallisation from light petroleum (b. p. 60—80°) gave prisms, m. p. 103° (Found: C, 56·0; H, 9·3; N, 16·45. $C_8H_{16}O_2N_2$ requires C, 55·8; H, 9·35; N, 16·3%). Di-4-morpholinyl is freely soluble in most solvents, including water, from which it can be partially salted out; it is slightly volatile in steam and reduces ammoniacal silver nitrate. It will not quaternise with methyl iodide, a behaviour also found with 4-phenylmorpholine. The salts are in general very soluble, except the *picrate*, large pale yellow prisms (from ethanol or water), m. p. 218° (Found: C, 41·35; H, 4·7; N, 17·6. $C_{12}H_{19}O_9N_5$ requires C, 41·8; H, 4·75; N, 17·4%).

Treatment of the washings of the crude dimorpholinyl with ethanolic picric acid, followed by water, gave a different *picrate* (*ca.* 2 g.), eventually obtained as bright yellow needles m. p. 184° (decomp.), from water (Found: C, 39·05; H, 4·4; N, 19·05. $C_{24}H_{32}O_{17}N_{10}$ requires C, 39·3; H, 4·4; N, 19·1%). The free base appeared to be a water-soluble oil, but was not characterised.

Addition of acetic acid to the alkaline aqueous portion from the reaction, followed by benzaldehyde, gave a precipitate of 4-benzylideneaminomorpholine (36 g.). Solutions of 4-aminomorpholine, after a few hours in air, do not show certain characteristic reactions, *e.g.*, formation of the benzylidene derivative, or Schotten–Baumann benzoylation. Reaction can be started by adding a trace of reducing agent, *e.g.*, sodium sulphite, or by boiling the solution (perhaps to expel dissolved oxygen) and cooling, before adding the other reagent.

Di-4-morpholinyl was also formed (13% yield) when 4-aminomorpholine sulphate (7·5 g.), di-(2-chloroethyl) ether (7 g.), sodium hydroxide (6 g.), and water (50 c.c.) were refluxed for 12 hr.

IMPERIAL CHEMICAL INDUSTRIES LIMITED, DYESTUFFS DIVISION,
HEXAGON HOUSE, BLACKLEY, MANCHESTER, 9. [*Received, August 25th*, 1955.]

159. *Heptadecafluorodecahydroquinoline and Perfluorotetradecahydroanthracene.*

By R. N. HASZELDINE and F. SMITH.

THE cobalt fluoride technique, used earlier for the preparation of monocyclic nitrogenous perfluoro-compounds,[1] has now been applied to the preparation in low yield of heptadecafluorodecahydroquinoline. Appreciable cleavage of the nitrogenous ring occurs when quinoline is passed over cobalt trifluoride, since perfluoro(-*n*-propyl*cyclo*hexane), perfluoro(methyl*cyclo*hexane), and perfluoro*cyclo*hexane were also produced. Perfluoro*cyclo*hexylamine was not detected and it is clear that fission of the C–N bond occurs preferentially at the ring junction. Analysis distinguishes between heptadecafluorodecahydroquinoline and a compound such as perfluoro-(3-*cyclo*hexylpropyl)difluoramine whose formation might have followed C–N fission. The boiling points of heptadecafluorodecahydroquinoline (130°) and perfluorotetrahydronaphthalene (142°) are similar and again illustrate that replacement of carbon in a fluorocarbon by nitrogen has only a slight effect on the boiling point.[1] Heptadecafluorodecahydroquinoline is stable to aqueous alkali, aqueous acid, potassium permanganate, zinc and refluxing ethanol, mercury, and ultraviolet light, and the N–F bond is thus not reactive.

Perfluorotetradecahydroanthracene has also been obtained; McBee and Bechtol[2]

[1] Haszeldine, *J.*, 1950, 1966; 1951, 102.
[2] McBee and Bechtol, *Ind. Eng. Chem.*, 1947, **39**, 380.

fluorinated anthracene, but the analytical data and physical properties of their product suggest the presence of appreciable impurity.

Experimental.—Fluorination of quinoline. The apparatus and techniques used have been described earlier.[2] Quinoline (284 g.), passed over cobalt trifluoride (equivalent to 175 g. of available fluorine) at 400° at an average rate of 10 g./hr., gave liquid products (158 g.). These were extracted with ethanol,[2] and then distilled (P_2O_5) through a packed column to give perfluoro*cyclo*hexane (1 g.) (Found: *M*, 298), b. p. 50—55°; perfluoro(methyl*cyclo*hexane) (1 g.) (Found: *M*, 351), b. p. 75—76°; and a fraction (51 g.), b. p. 120—135°. The identity of the perfluoro*cyclo*hexane and perfluoro(methyl*cyclo*hexane) was confirmed spectroscopically. The fraction, b. p. 120—135°, was treated with uranium hexafluoride and then redistilled through a 28-plate column to give perfluoro(propyl*cyclo*hexane) (1·5 g.) (Found: C, 23·9%; *M*, 447. Calc. for C_9F_{18}: C, 24·0%; *M*, 450), b. p. 124·2—125·2°, n_D^{25} 1·294, spectroscopically identical with a known sample,[2] and *heptadecafluorodecahydroquinoline* (15·5 g., 2%), b. p. 130·4, n_D^{25} 1·302 [Found: C, 24·6; N, 2·9, 3·2, 3·1; F, 72·1%; *M*, 444, 454. C_9NF_{17} requires C, 24·3; N, 3·1; F, 72·6%; *M*, 445. Calc. for perfluoro-(3-*cyclo*hexylpropyl)difluoramine: C, 22·4; N, 2·9; F, 74·7%; *M*, 483], shown spectroscopically to be free from C–H bonds.

Fluorination of anthracene. Anthracene (56 g.), was added in 5-g. portions (7·5 hr.) to a cobalt trifluoride reaction vessel (400 g. of available fluorine) heated to 350° at the inlet and 450° at the outlet. Distillation of the product gave perfluorotetradecahydroanthracene (10% yield) [Found: C, 26·6; F, 72·4%; *M* (ebullioscopic in perfluoromethyl*cyclo*hexane), 630. Calc. for $C_{14}F_{24}$: C, 26·9; F, 73·1%; *M*, 624], b. p. 205—206°, m. p. 155° (sealed tube), as a white shining solid which readily sublimed at 60°/760 mm., and was spectroscopically free from C–H bonds.

A. E. Hills Laboratories, University of Birmingham.
University Chemical Laboratory, Cambridge. [*Received, September 8th*, 1955.]

[2] Haszeldine and Smith, *J.*, 1950, 3617, 2689.

160. *Adsorption of Binary Liquid Mixtures on Solid Adsorbents.*

By G. S. Mill.

Considering the adsorption of two completely miscible liquids, A and B, on a solid surface, Elton [1] derived an equation for the calculation of the mole fraction of B on the surface. He gave this equation originally as

$$x_B^s = n_B^s/(n_A^s + n_B^s) = \frac{Ax_B - a_A(n_A + n_B)\Delta x_B}{A + (n_A + n_B)(a_B - a_A)\Delta x_B} \quad . \quad . \quad . \quad . \quad (1)$$

where n_A^s and n_B^s are the numbers of moles of A and B in the surface layer at equilibrium, n_A and n_B are the total numbers of moles of A and B present in the system, x_B is the mole fraction of B in the bulk liquid at equilibrium, Δx_B is defined as $x_B - x_B^0$ where x_B^0 is the mole fraction of B before adsorption, a_A and a_B are the effective areas occupied per mole of A and B, and A is the area of the surface available for adsorption.

This equation was later [2] corrected to:

$$x_B^s = n_B^s/(n_A^s + n_B^s) = \frac{A(x_B + \Delta x_B) - a_A(n_A + n_B)\Delta x_B}{A + (n_A + n_B)(a_B - a_A)\Delta x_B} \quad . \quad . \quad . \quad (2)$$

The original equation [eqn. (1) above] is correct, and incidentally can be obtained by a simpler method than that employed by Elton. The general equation describing the adsorption of two miscible liquids, A and B, on a solid surface was first given by Williams [3] and can be written in the form:

$$(n_A + n_B)\Delta x_B = n_A^s x_B - n_B^s(1 - x_B) \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Elton's equation (1) was

$$n_A^s a_A + n_B^s a_B = A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

[1] Elton, *J.*, 1951, 2958.
[2] Errata, *J.*, 1952, March, xiii; Elton, *J.*, 1952, 1955.
[3] Williams, *Medd. K. Vetenshapsakad. Nobelinst.*, 1913, **2**, No. 27.

If equations (3) and (4) are then solved for n_A^s and n_B^s and the resulting expressions are substituted in the equation $x_B^s = n_B^s/(n_A^s + n_B^s)$, equation (1) above results. The mistake in Elton's derivation (as corrected by him) is algebraic and lies in the steps involved between his equations (9) and (10).

THE RICE INSTITUTE, HOUSTON, TEXAS. [*Received, September 12th*, 1955.]

161. *Reaction of Tellurium Dioxide and Selenium Tetrafluoride: Preparation of Tellurium Tetrafluoride.*

By R. CAMPBELL and P. L. ROBINSON.

TELLURIUM TETRAFLUORIDE was reported by Hartley, Henry, and Whytlaw-Gray [1] as a white solid resulting from the reduction of the hexafluoride with elementary tellurium. (Berzelius [2] mistakenly thought he had made it from hydrofluoric acid and tellurium dioxide, and Moissan [3] by the action of fluorine on tellurium; Prideaux [4] showed the latter must have had hexafluoride.) The reduction of the hexafluoride was subsequently investigated in these laboratories and is described by Peacock,[5] who gave details of an apparatus which allowed the reduction to take place in alumina and the tetrafluoride subsequently to be transferred to glass for storage. Colourless, needle-shaped crystals of the pure substance were obtained; but the method involved a reaction-time of four days and allowed only a small quantity to be made per run. Junkins, Bernhardt, and Barber,[6] carrying out the same reaction later in a nickel vessel for periods of over 100 hr., obtained a product of average composition Te, 62·06; F, 36·04%. Neither the reduction of hexafluoride nor the action of nitryl fluoride on tellurium [7] furnishes a method of preparing the tetrafluoride comparable in convenience with that now described.

The ease with which selenium tetrafluoride is converted into the oxyfluoride, $SeOF_2$, and the fact that the latter is readily volatilised, b. p. 126°, led us to examine its reaction with the tellurium oxides. The trioxide appears to be unreactive at least up to the boiling point of selenium tetrafluoride, b. p. 93°, but at about 80° the dioxide reacts smoothly and quantitatively according to the scheme $TeO_2 + 2SeF_4 \longrightarrow TeF_4 + 2SeOF_2$. In this way the whole of the dioxide is converted into tetrafluoride which can readily be recovered in a pure crystalline condition by evaporating the excess of selenium tetrafluoride and the selenium oxyfluoride.

Experimental.—Selenium tetrafluoride, readily preparable in bulk, was distilled from a break-seal storage bulb into a carefully dried, evacuated train of bulbs, the stem of the first, which carried the dry tellurium dioxide, being drawn down for subsequent removal under vacuum. The liquid was condensed on to the dioxide and the mixture was slowly heated by means of a water-bath. As the temperature approached 80° there was a vigorous but steady reaction and the tellurium dioxide dissolved. The temperature was raised until the liquid began to reflux under its own vapour pressupe and kept at that point for 15 min., after which the selenium tetrafluoride and oxyfluoride were distilled into another bulb, the last traces being removed from the residue by keeping it at 100° and 10^{-2} mm. for 1 hr. The product was wholly crystalline (Found: Te, 62·6; F, 37·1. Calc. for TeF_4: Te, 62·7; F, 37·3%).

The authors acknowledge grants for material and maintenance (R. C.) from the United Kingdom Atomic Energy Authority.

KING'S COLLEGE, NEWCASTLE UPON TYNE, 1. [*Received, September 14th*, 1955.]

[1] Hartley, Henry, and Whytlaw-Gray, *Nature*, 1938, **142**, 952.
[2] Berzelius, *Schweigger's J.*, 1812, **6**, 311.
[3] Moissan, *Ann. Chim. Phys.*, 1891, **24**, 239.
[4] Prideaux, *J.*, 1906, **89**, 316.
[5] Peacock, Ph.D. Thesis, Univ. Durham, 1951.
[6] Junkins, Bernhardt, and Barber, *J. Amer. Chem. Soc.*, 1952, **74**, 5749.
[7] Aynsley, Hetherington, and Robinson, *J.*, 1954, 1119.

162. *Preparation and Some Properties of 2 : 2′-Dibromodiphenylamine.*

By Emrys R. H. Jones and Frederick G. Mann.

Failure attended our attempts to prepare 2 : 2′-dibromodiphenylamine by (*a*) heating *o*-bromoaniline and its hydrochloride (1 mol. each) at 235—240° in open or sealed tubes, (*b*) heating *o*-chloronitrobenzene (1 mol.) and *o*-bromoaniline (1·5 mol.) with potassium carbonate and copper bronze at 170° for various times up to 12 hr., (*c*) heating *o*-bromophenol [1] with 1 and 2 equivs., respectively, of *o*-bromoaniline and zinc chloride at 250° for 8 hr., (*d*) boiling a mixture of *o*-chloronitrobenzene and *o*-bromo-*N*-sodioacetanilide in xylene for 3 hr., and (*e*) acylating or methylating the intermediate 2 : 2′-dinitrodiphenylamine [2] under a variety of conditions. The methods (*a*), (*b*), and (*c*) gave only intractable tars, and the product from method (*d*) when worked up yielded *o*-bromoacetanilide in 50% recovery.

The amine was ultimately prepared by using the Chapman rearrangement.[3] *o*-Bromobenzanilide was converted by phosphorus pentachloride into *N*-*o*-bromophenylbenzimidoyl chloride (I), which with sodium *o*-bromophenoxide gave *o*-bromophenyl *N*-*o*-bromophenylbenzimidoate (II). This ester, when suitably heated, rearranged to *N*-benzoyl-2 : 2′-dibromodiphenylamine (III), which on alkaline hydrolysis gave 2 : 2′-dibromodiphenylamine; this exists in dimorphic forms, m. p. 37° and 61°.

$$\underset{\text{(I)}}{Br\cdot C_6H_4\cdot N{:}CClPh} \longrightarrow \underset{\text{(II)}}{Br\cdot C_6H_4\cdot N{:}CPh\cdot O\cdot C_6H_4Br} \longrightarrow \underset{\text{(III)}}{(Br\cdot C_6H_4)_2N\cdot COPh}$$

This amine resisted methylation: it was unaffected when its solution in formic acid–formaldehyde was boiled for 7 hr., and when heated with methyl sulphate at 100° for 1 hr. It rapidly decomposed to a black tar when its solution in methyl sulphate was boiled.

It underwent ready lithiation when its ethereal solution was treated with *n*-butyllithium in light petroleum. Carboxylation of the product afforded diphenylamine-2 : 2′-dicarboxylic acid in 84% yield.

2 : 2′-Dilithiodiphenyl ether condenses with phenyldichlorophosphine to give 10-phenylphenoxphosphine [4] in 63% yield, but the lithium derivative of diphenylamine reacted with the phosphine to give a sticky solid, presumably a polymer, which had an indefinite m. p., was freely soluble in chloroform and benzene and very sparingly soluble in most solvents, could not be obtained crystalline, and could not be broken down by pyrolysis [5] (at atmospheric or reduced pressure) to simpler, identifiable compounds. Its solution in boiling methyl iodide gave an intractable gummy product.

This extensive polymerisation might have been avoided had preliminary protection of the amine group been possible. If so, the reaction would have afforded ready access to 5 : 10-dihydro-10-phenylphenphosphazine and thus indirectly to many of its derivatives. Michaelis and Schenk,[6] and later Sergeev and Kudryashov,[7] prepared the crude 10-chloro-5 : 10-dihydrophenphosphazine by direct condensation of diphenylamine with phosphorus trichloride, and then by hydrolysis obtained the pure 10-hydroxy-derivative. We have investigated this condensation employing a wide variation of trichloride proportions (1·0—2·8 mols.), catalyst, solvent, temperature, and time of heating, but have obtained after hydrolysis only very low yields of the 10-hydroxyphosphazine: moreover the crude condensation product, if prepared on a reasonably large scale, may cause explosions when subsequently extracted with water. Phosphorus trichloride had no action on *N*-methyldiphenylamine, and in this respect resembles arsenic trichloride.[8]

[1] Merz and Weith, *Ber.*, 1880, **13**, 1299.
[2] Eckert and Steiner, *Monatsh.*, 1914, **35**, 1154.
[3] Chapman, *J.*, 1929, 569; also *J.*, 1922, **121**, 1676; 1925, **127**, 1992; 1927, 1743.
[4] Mann and Millar, *J.*, 1953, 3746.
[5] Cf. Beeby and Mann, *J.*, 1951, 886; Mann, Millar, and Stewart, *J.*, 1954, 2832.
[6] Michaelis and Schenk, *Annalen*, 1890, **260**, 1.
[7] Sergeev and Kudryashov, *J. Gen. Chem.* (*U.S.S.R.*), 1938, **8**, 266.
[8] Burton and Gibson, *J.*, 1926, 450.

Experimental.—N-*o*-*Bromophenylbenzimidoyl chloride* (I). Powdered *o*-bromobenzanilide (446 g.) was mixed with phosphorus pentachloride (360 g., 1·05 mols.) in a flask through which nitrogen was passed. On this scale the reaction began spontaneously, but on a smaller scale required gentle initial heating. When the vigorous reaction had subsided, the mixture was heated at 100° for *ca.* 10 min., and the phosphorus oxychloride then removed by distillation (water-pump); the residue, distilled at lower pressure, gave the *imidoyl chloride* (I), b. p. 164—168°/2 mm. (408 g., 86%); a sample, further purified by fractionation, had b. p. 123—125°/0·02 mm. (Found: C, 53·0; H, 2·85. $C_{13}H_9NClBr$ requires C, 53·0; H, 3·1%). The m. p. of the pure compound is just below room temperature.

o-Bromophenyl N-*o-bromophenylbenzimidoate* (II). *o*-Bromophenol (63 g.) was added to a solution obtained by the interaction of sodium (8·4 g., 1 atom-equiv.) and absolute ethanol (500 c.c.), which was then thoroughly cooled and stirred whilst a solution of the imidoyl chloride (I) (108 g., 1 mol.) in ether (200 c.c.) was added. Next day, the greater part of the solvent was removed by distillation, and the residue poured into water, precipitating the *ester* (II) as an oil which slowly solidified. Recrystallisation from ethanol gave colourless crystals, m. p. 95° (Found: C, 53·0; H, 3·0; N, 3·4. $C_{19}H_{12}ONBr_2$ requires C, 52·9; H, 3·0; N, 3·25%): 76 g., 48% yield.

N-*Benzoyl*-2 : 2′-*dibromodiphenylamine* (III). The exothermic rearrangement of the ester (II) was markedly affected by small changes in the temperature, and the optimum conditions were therefore determined largely by the scale of the experiment. Three results are quoted for illustration. (i) The ester (7·3 g.) was heated for 3 hr. at 265—270° (bath-temp.) and the product digested with boiling ethanol (20 c.c.). The benzoyl derivative (III) which separated on cooling had m. p. 172—177° (4·3 g., 58%). (ii) The ester (40 g.), heated at 155—260°/2·5 hr. and digested with ethanol (90 c.c.), gave the derivative (III), m. p. 175—179° (26 g., 65%). (iii) The ester (35 g.), heated as in (ii) and digested with ethanol (50 c.c.), gave the derivative (III), m. p. 175—179° (30 g., 86%). Recrystallisation from ethanol gave the pure *benzoyl* derivative (III), m. p. 179—180° (Found: C, 53·1; H, 3·3; N, 3·35. $C_{19}H_{12}ONBr_2$ requires C, 52·9; H, 3·0; N, 3·25%).

2 : 2′-*Dibromodiphenylamine*. The derivative (III) (75 g.) was boiled in a solution of potassium hydroxide (150 g.) in water (150 c.c.) and ethanol (750 c.c.) for 8 hr. and then concentrated by distillation, the residue being poured into water. The precipitated oil was extracted with ether, and the dried extract on distillation gave the *amine*, b. p. 135—142°/0·05 mm. (46·0 g., 87%). The amine when first prepared was isolated as colourless crystals, m. p. 37°, by crystallisation from ethanol at −70°: this sample, when set aside for 2 weeks, had changed to yellow crystals, m. p. 61°. All subsequent preparations furnished solely the yellow crystals, m. p. 61°, readily isolated by normal crystallisation from ethanol (Found: C, 44·3; H, 2·8; N, 4·3. $C_{12}H_9NBr_2$ requires C, 44·0; H, 2·8; N, 4·3%).

Lithiation. The amine (5·0 g.) in ether (50 c.c.) was added under nitrogen to a stirred 0·66N-solution of *n*-butyl-lithium in light petroleum (b. p. 40—60°) (120 c.c.; 6 mols. of solute), which after 10 min. was poured on crushed solid carbon dioxide (*ca.* 50 g.). The mixture was ultimately extracted with dilute aqueous potassium hydroxide, which when separated and acidified gave diphenylamine-2 : 2′-dicarboxylic acid, yellow crystals, m. p. 291° (decomp.), from ethanol (Found: C, 65·6; H, 4·6; N, 5·4. Calc. for $C_{14}H_{11}O_4N$: C, 65·3; H, 4·3; N, 5·4%); the yield of recrystallised product was 2·85 g. (84%). Ullmann [1] records the acid as forming yellow crystals, m. p. 295° (decomp.).

Reaction with phenyldichlorophosphine. The amine (5·0 g.) was lithiated by using a 0·83N-solution of *n*-butyl-lithium (57 c.c.; 3·1 mols. of solute) under the above conditions, and then treated with the phosphine (2·74 g., 1 mol.) in ether (25 c.c.), a vigorous reaction occurring with deposition of an orange solid. The mixture was boiled under reflux for 1 hr., and then cooled and hydrolysed with water (100 c.c.). The insoluble product, now yellow, was collected, washed, and dried; it softened between *ca.* 80° and *ca.* 200°, becoming ultimately a viscous liquid. Its general properties are indicated above. When the solution of the lithiated amine was cooled in acetone–solid carbon dioxide before addition of the phosphine, the same product was obtained.

Tests kindly undertaken by Mr. O. D. Standen at the Wellcome Laboratories of Tropical Medicine have shown that 5 : 10-dihydro-10-hydroxyphenphosphazine has no apparent effect on schistosomiasis infection in mice.

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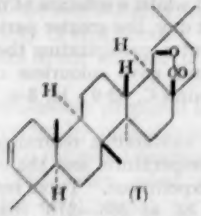
University Chemical Laboratory, Cambridge. [*Received, September 15th*, 1955.]

[1] Ullmann, *Annalen*, 1907, **355**, 352.

163. *Triterpenoids. Part XXI.* A Triterpenoid Lactone from Petroleum.*

By D. H. R. Barton, W. Carruthers, and K. H. Overton.

Recently Carruthers and Cook [1] reported some preliminary investigations on the constituents of high-boiling petroleum distillates. Amongst the compounds isolated was a high-melting crystalline substance of the approximate composition, $C_{30}H_{46}O_2$. With the kind permission of Dr. J. W. Cook, F.R.S., we have examined this substance and identified it as oxyallobetul-2-ene (I). An authentic specimen was prepared by the



(I)

(II)

pyrolysis of oxyallobetulin benzoate (II).[2] The identification of this petroleum constituent as a derivative of the typical plant triterpenoid, betulin, shows that at least a small proportion of the petroleum must have been of vegetable rather than animal origin.[3]

Experimental.—Rotations were measured in chloroform solution. Ultraviolet absorption spectra were determined in ethanol with the Unicam S.P. 500 Spectrophotometer. The infrared spectra were taken in Nujol mulls, a Perkin-Elmer double-beam instrument Model 13 being used. All m. p.s were observed in evacuated capillaries.

Oxyallobetulin benzoate. Treatment of oxyallobetulin, m. p. *ca.* 330°, $[\alpha]_D$ +49° (*c*, 0·92), with pyridine–benzoyl chloride overnight at room temperature gave *oxyallobetulin benzoate*, m. p. (plates from chloroform–methanol) 345—348°, $[\alpha]_D$ +71° (*c*, 3·33), $\lambda_{max.}$ 230 mμ (ε, 13,500) (Found: C, 79·45; H, 9·3. $C_{37}H_{52}O_4$ requires C, 79·25; H, 9·35%).

Pyrolysis of oxyallobetulin benzoate. The benzoate (250 mg.) was pyrolysed at 550°/0·2 mm. in a stream of oxygen-free nitrogen (approx. ½ l. per hr. at room temperature and atmospheric pressure).[4] The product was refluxed with 5% ethanolic potassium hydroxide (20 ml.) for 1 hr. Most of the ethanol was removed *in vacuo*, and the residue acidified (5N-sulphuric acid) and extracted with ether. Removal of the ether *in vacuo* and chromatography of the residue in benzene solution on alumina gave *oxyallobetul-2-ene* (long plates from chloroform–methanol), sublimed below 345° after insertion at 310°, $[\alpha]_D$ +79° (*c*, 1·18) λ_{210} and λ_{206} mμ, ε = 750 and 1450, respectively) (Found: C, 82·2; H, 10·2. $C_{30}H_{46}O_2$ requires C, 82·15; H, 10·55%).

The compound isolated by Carruthers and Cook (*loc. cit.*) and for which they reported C, 81·8, 81·6; H, 10·7, 10·8 was repeatedly recrystallised from chloroform–methanol. It was identified as oxyallobetul-2-ene by crystal form, m. p. (sublimed by 345° after insertion at 310°; same behaviour on admixture with authentic material), rotation {$[\alpha]_D$ +75° (*c*, 0·68)}, ultraviolet absorption spectrum (λ_{210} and λ_{206} mμ, ε = 700 and 1350; similar identity at other wavelengths below 220 mμ), and infrared spectrum.

We thank the Government Grants Committee of the Royal Society and Imperial Chemical Industries Limited for financial assistance. One of us (W. C.) has been supported by the Medical Research Council. We acknowledge with gratitude the interest and encouragement of Dr. J. W. Cook, F.R.S. The infrared spectra were determined by Dr. G. Eglinton and the microanalyses were by Mr. J. M. L. Cameron.

The University, Glasgow, W.2. [*Received, September 22nd,* 1955.]

* Part XX, *J.*, 1955, 2639.

[1] Carruthers and Cook, *J.*, 1954, 2047.
[2] See Davy, Halsall, Jones, and Meakins, *J.*, 1951, 2702.
[3] Cf. van Nes and van Westen, "Aspects of the Constitution of Mineral Oils," Elsevier Publishing Co., Amsterdam, 1951, p. 43.
[4] See Barton and de Mayo, *J.*, 1954, 887.

164. *Deoxy-sugars. Part XXX.* Synthesis and Characterization of Derivatives of 2-Deoxy*aldehydo-D-*galactose and its 2-Deoxy-*D-*glucose Analogue.*

By J. L. Barclay, A. J. Cleaver, A. B. Foster, and W. G. Overend.

Considerable use has been made of derivatives of 2-deoxy*aldehydo*-D-galactose and of 2-deoxy*aldehydo*-D-glucose as model compounds in studies of the synthesis of 2-deoxy-sugar nucleotides.[1,2] We now describe improved methods for the preparation and characterization of 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy*aldehydo*-D-galactose and its 2-deoxy-*aldehydo*-D-glucose analogue.

2-Deoxy-D-galactose [3] was readily converted into the diethyl dithioacetal which could also be obtained (but in lower yield) directly from D-galactal by treatment successively with ethanethiol and hydrochloric acid. Likewise 2-deoxy-D-galactose dibenzyl dithioacetal could be obtained from D-galactal. The diethyl dithioacetal was converted into a syrupy 3 : 4 : 5 : 6-tetra-acetate which on treatment with mercuric chloride and cadmium carbonate [1,4] afforded crystalline 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy*aldehydo*-D-galactose. In a similar manner 3 : 4 : 5 : 6-tetra-*O*-acetyl-2-deoxy*aldehydo*-D-glucose was obtained from 2-deoxy-D-glucose.[5]

Very few derivatives have been reported of 2-deoxy*aldehydo*-sugars. 2-Deoxy-D-glucose dimethyl acetal has been described [6] and recently some phosphoric esters of 2-deoxy*aldehydo*hexoses were described by Barclay, Foster, and Overend.[1]

No crystalline product could be obtained by reaction of the 2-deoxy*aldehydo*-sugar derivatives with aniline under a variety of conditions but condensation with 2 : 4 : 1-xylidine or *o*-phenylenediamine afforded amorphous, pale yellow solids of ill-defined composition. A detailed study of the reaction of some *aldehydo*-sugars with primary aromatic amines has been published.[2]

The 2-deoxy*aldehydo*-D-glucose derivative was characterized as the semicarbazone.[7] Both the 2-deoxy*aldehydo*-D-glucose and -D-galactose derivatives gave crystalline 2 : 4-dinitrophenylhydrazones and the glucose derivative gave a bisdimedone.

Experimental.—*2-Deoxy-D-galactose diethyl dithioacetal.* Finely powdered 2-deoxy-D-galactose (5·0 g.) was dissolved in concentrated hydrochloric acid (5 ml.) at 0°, and ethanethiol (10 ml.) was added. After the mixture had been shaken for 12 hr. (at room temperature) the product was isolated in the usual fashion. After recrystallization from water the diethyl dithioacetal (5·5 g., 67%) was obtained as plates, m. p. 107—108°, $[\alpha]_D$ +18° (*c*, 1·0 in MeOH) (Overend, Shafizadeh, and Stacey [3] give m. p. 107—108°). The same product was prepared directly from D-galactal (1·0 g.) by successive treatment with ethanethiol (2 ml.) and concentrated hydrochloric acid (2 ml.). The reactants were cooled (ice–salt) before being mixed. Reaction was allowed to proceed at room temperature for 2 hr. before the product (0·6 g., 32%; m. p. 108°) was isolated.

3 : 4 : 5 : 6-*Tetra*-O-*acetyl*-2-*deoxy*-D-*galactose diethyl dithioacetal.* This *tetra-acetyl derivative*, prepared from 2-deoxy-D-galactose diethyl dithioacetal (2·0 g.) (yield; Ac_2O–C_5H_5N method, 2·38 g., 73%; NaOAc–Ac_2O method, 2·70 g., 83%) formed a viscous syrup, b. p. 167—172° (bath)/0·016 mm., n_D^{19} 1·4852, $[\alpha]_D^{16}$ +31·5° (*c*, 1·65 in $CHCl_3$) (Found: C, 49·2; H, 6·9; S, 14·3. $C_{18}H_{30}O_8S_2$ requires C, 49·3; H, 6·9; S, 14·6%).

3 : 4 : 5 : 6-*Tetra*-O-*acetyl*-2-*deoxy*aldehydo-D-*galactose.* 3 : 4 : 5 : 6-Tetra-*O*-acetyl-2-deoxy-D-galactose diethyl dithioacetal (3·44 g.) in acetone (50 ml.) and water (25 ml.) was treated with a ten-fold excess of finely powdered cadmium carbonate (13·5 g.). The suspension was well stirred and a solution of mercuric chloride (9·0 g.) in acetone (25 ml.) was added dropwise

* Part XXIX, *J.*, 1955, 2511.

[1] Barclay, Foster, and Overend, *J.*, 1955, 2505.
[2] *Idem*, *J.*, 1956, 476.
[3] Cf. Overend, Shafizadeh, and Stacey, *J.*, 1950, 671.
[4] Wolfrom, Konigsberg, and Weisblat, *J. Amer. Chem. Soc.*, 1939, **61**, 574.
[5] Cf. Overend, Stacey, and Staněk, *J.*, 1949, 2841.
[6] Bolliger and Schmid, *Helv. Chim. Acta*, 1951, **34**, 989, 1597, 1671.
[7] Wolfrom, *J. Amer. Chem. Soc.*, 1929, **51**, 2188.

during 1 hr. Stirring was continued for a further 24 hr. and then the mixture was filtered on to a small amount of cadmium carbonate. The filtrate was evaporated to dryness under diminished pressure in the presence of fresh cadmium carbonate (10 g.). The residue was extracted with hot chloroform (2 × 50 ml.), and the extract was washed with water (3 × 100 ml.), 5% potassium iodide solution (3 × 100 ml.), and water, and then dried (Na_2SO_4). Evaporation of the solvent and recrystallization of the residue from acetone–light petroleum (b. p. 60—80°) afforded 3 : 4 : 5 : 6-*tetra*-O-*acetyl*-2-*deoxy*aldehydo-D-*galactose* (1·42 g., 43%) as needles, m. p. 87—88°, $[\alpha]_D^{18}$ +52·0° (*c*, 1·12 in $CHCl_3$) (Found : C, 50·3; H, 5·9. $C_{14}H_{20}O_9$ requires C, 50·6; H, 6·0%). On storage slow decomposition occurred. This product (0·21 g.) readily gave a 2 : 4-dinitrophenylhydrazone (0·24 g.), m. p. 110° (sinter, 102—104°), $[\alpha]_D^{16}$ +21·6° (*c*, 1·48 in $CHCl_3$) (Found : C, 47·0; H, 4·8; N, 11·2. $C_{20}H_{24}O_{12}N_4$ requires C, 46·9; H, 4·7; N, 10·9%).

3 : 4 : 5 : 6-*Tetra*-O-*acetyl*-2-*deoxy*aldehydo-D-*glucose*. 2-Deoxy-D-glucose diethyl dithioacetal {m. p. 134°; $[\alpha]_D^{19}$ +10° (*c*, 1·0 in EtOH); 8 g.} was acetylated with acetic anhydride in pyridine (yield 12 g., 92%). The acetate {m. p. 77°, $[\alpha]_D^{18}$ +35° (*c*, 2·2 in $CHCl_3$); 6·9 g.} was dissolved in acetone (50 ml.) and water (20 ml.), and powdered cadmium carbonate (35 g.) was added, followed by mercuric chloride (30 g.) in acetone (40 ml.), added slowly. Reaction was allowed to proceed for 20 hr., and more cadmium carbonate was added at intervals. The product was isolated as described previously; 3 : 4 : 5 : 6-*tetra*-O-*acetyl*-2-*deoxy*aldehydo-D-*glucose* (5·2 g., 56%) was obtained as long needles, m. p. 100°, $[\alpha]_D^{14}$ +23° (*c*, 1·5 in $CHCl_3$) (Found : C, 50·7; H, 6·3. $C_{14}H_{20}O_9$ requires C, 50·6; H, 6·0%). The material slowly became discoloured, and acetic acid was liberated. The product was readily converted into a *semicarbazone*, m. p. 158°, $[\alpha]_D^{16}$ +50° (*c*, 1·0 in $CHCl_3$) (Found : C, 46·5; H, 6·1; N, 10·5. $C_{15}H_{23}O_9N_3$ requires C, 46·3; H, 5·9; N, 10·8%), and a 2 : 4-*dinitrophenylhydrazone*, m. p. 131°, $[\alpha]_D^{15}$ +45° (*c*, 0·4 in $CHCl_3$) (Found : C, 46·8; H, 4·6; N, 11·3. $C_{20}H_{24}O_{12}N_4$ requires C, 46·9; H, 4·7; N, 10·9%).

3 : 4 : 5 : 6-Tetra-*O*-acetyl-2-deoxy*aldehydo*-D-glucose (120 mg.) and dimedone (130 mg.) were heated for 5 min. in 50% aqueous ethanol and the solution was then set aside overnight. Water was added until the solution became turbid, and the *bisdimedone* (95 mg.) which separated at 0° was crystallized from aqueous ethanol; it had m. p. 110°, $[\alpha]_D^{17}$ −30° (*c*, 1·0 in $CHCl_3$) (Found : C, 60·5; H, 7·0. $C_{30}H_{42}O_{12}$ requires C, 60·6; H, 7·1%).

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165. *The Synthesis and Reactions of* 3-iso*Hexyl*-3-*methyl*cyclo*hexanone.*

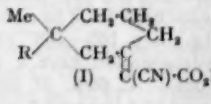
By (MISS) USHA RAKSHIT, K. C. BHATTACHARYYA, and J. C. BARDHAN.

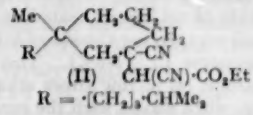
By Kharasch and Tawney's method reaction between *iso*hexylmagnesium iodide and 3-methyl*cyclo*hex-2-enone in presence of cuprous chloride gave an excellent yield of a saturated ketone (semicarbazone and 2 : 4-dinitrophenylhydrazone) which was shown as follows to be the expected 3-*iso*hexyl-3-methyl*cyclo*hexanone. αα′-Dicyano-β-*iso*hexyl-β-methylglutarimide [2] was hydrolysed with 60% sulphuric acid to give β-*iso*hexyl-β-methylglutaric acid, the anhydride of which was converted into the half-ester and thence through the acid chloride and methylzinc iodide into ethyl 3-*iso*hexyl-3-methyl-5-oxohexanoate. The latter when heated with ethanolic sodium ethoxide afforded 5-*iso*hexyl-5-methyl*cyclo*hexane-1 : 3-dione, yielding on treatment with phosphorus trichloride,[3] followed by hydrogenation,[4] 3-*iso*hexyl-3-methyl*cyclo*hexanone, identical with the ketone described above. Alternatively, the substituted glutaric anhydride on reduction with sodium and ethanol [5] gave β-*iso*hexyl-β-methyl-δ-valerolactone, which was converted, by means of

[1] Kharasch and Tawney, *J. Amer. Chem. Soc.*, 1941, **63**, 2308; Birch and Robinson, *J.*, **1943**, 501; Büchi, Jeger, and Ruzicka, *Helv. Chim. Acta*, 1948, **31**, 245.
[2] Guareschi, *Mem. Real. Acad. Sci. Torino*, 1901, **50**, 235.
[3] Crossley and Le Sueur, *J.*, 1902, **81**, 675, 821; 1903, **83**, 117.
[4] France, Heilbron, and Hey, *J.*, 1939, 1290.
[5] Blanc, *Bull. Soc. chim. France*, 1905, **33**, 879.

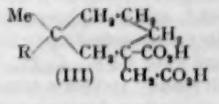
phosphorus pentabromide and then ethanol, into ethyl δ-bromo-β-*iso*hexyl-β-methylvalerate; chain extension by use of malonic ester then gave β-*iso*hexyl-β-methylpimelic acid, which on ketonisation afforded the required *cyclo*hexanone.

The ketone was condensed with ethyl cyanoacetate [6] in presence of ammonium acetate and acetic acid to give α-cyano-α-(3-*iso*hexyl-3-methyl*cyclo*hexylidene)acetate (I), which


(I) $C(CN)\cdot CO_2Et$


(II) $CH(CN)\cdot CO_2Et$

$R = \cdot[CH_2]_3\cdot CHMe_2$


(III) $CH_2\cdot CO_2H$

formed an additive compound (II) with hydrogen cyanide.[7] The latter on hydrolysis yielded the corresponding dicarboxylic acid (III) as a viscous liquid.

Experimental.—3-Methyl*cyclo*hex-2-enone [8] was prepared by condensation of paraformaldehyde (12 g.) with ethyl acetoacetate (104 g.) in presence of piperidine (4 ml.); it (23 g.) had b. p. 86—90°/13 mm.

3-iso*Hexyl*-3-*methyl*cyclo*hexanone*. A solution of *iso*hexylmagnesium iodide [activated magnesium (3·25 g.), *iso*hexyl iodide [9] (28 g.), dry ether (45 ml.)] was cooled in a freezing mixture and thoroughly mixed with dry powered cuprous chloride (0·2 g.), and then a solution of 3-methyl*cyclo*hex-2-enone (11 g.) in dry ether (15 ml.) was introduced with stirring, and the mixture set aside overnight. It was cooled in ice, mixed with a saturated solution of ammonium chloride (25 ml.), and acidified with dilute hydrochloric acid, and the liquid extracted with ether. The ethereal solution was washed with a solution of sodium thiosulphate and then with water, dried ($CaCl_2$), and distilled. 3-iso*Hexyl*-3-*methyl*cyclo*hexanone* formed a colourless liquid (11 g.), b. p. 135—140°/13 mm. (Found: C, 79·5; H, 12·1. $C_{13}H_{24}O$ requires C, 79·6; H, 12·2%). The *semicarbazone* separated from ethanol in plates, m. p. 169° (Found: C, 66·5; H, 10·6. $C_{14}H_{27}ON_3$ requires C, 66·4; H, 10·7%), and the 2 : 4-*dinitrophenylhydrazone* from light petroleum (b. p. 40—60°) or ethyl acetate in orange-red needles, m. p. 106° (Found: C, 60·5; H, 7·5. $C_{19}H_{28}O_4N_4$ requires C, 60·6; H, 7·4%).

β-iso*Hexyl*-β-*methylglutaric acid*. *iso*Hexyl methyl ketone,[10] b. p. 40—41°/4 mm., 167—168°/760 mm., was prepared by hydrogenation of methylheptenone,[11] b. p. 54—55°/3 mm. The ketone (128 g.), ethyl cyanoacetate (226 ml.), and ethanol (400 ml.), saturated with ammonia at 0°, gave when kept in the cold for 2 days αα′-dicyano-β-*iso*hexyl-β-methylglutarimide (193 g.), which crystallised from ethanol in plates, m. p. 168° (lit.,[3] 166·5—168·5°) (Found: C, 64·5; H, 7·4. Calc. for $C_{14}H_{19}O_2N_3$: C, 64·4; H, 7·3%). When a mixture of the imide (110 g.), concentrated sulphuric acid (330 ml.), and water (275 ml.) was refluxed for 12 hr., β-*iso*hexyl-β-methylglutaric acid (90 g.) was obtained, which crystallised from aqueous acetic acid in short prisms, m. p. 80—81° (lit.,[12] 62—63°) (Found: C, 62·4; H, 9·6. Calc. for $C_{13}H_{24}O_4$: C, 62·6; H, 9·6%). The *diethyl ester* had b. p. 142°/7 mm. (Found: C, 67·1; H, 10·6. $C_{18}H_{36}O_4$ requires C, 67·1; H, 10·5%). The *anhydride*, prepared by heating the acid with acetic anhydride, had b. p. 160°/7 mm., m. p. 39—41° (Found: C, 67·6; H, 9·4. $C_{13}H_{20}O_3$ requires C, 67·9; H, 9·4%).

Ethyl 3-iso*hexyl*-3-*methyl*-5-*oxohexanoate* (3 : 7-*dimethyl*-3-2′-*oxopropyloctanoate*). The foregoing anhydride (43·5 g.) was heated with absolute ethanol (23 ml.) on the steam-bath for 3 hr. The half-ester (48 g.), b. p. 178—180°/6 mm., was mixed with thionyl chloride (15 ml.), and after 3 hr. the mixture was heated at 45° for 1 hr., and the excess of thionyl chloride removed; the crude ester chloride, dissolved in benzene, was allowed to react with an excess of methylzinc iodide [from methyl iodide (55 ml.), ethyl acetate (25 ml.), benzene (70 ml.), and zinc–copper couple [13] (70 g.)]. The *keto-ester* had b. p. 135—137°/5 mm. (Found: C, 69·9; H, 10·6. $C_{15}H_{28}O_3$ requires C, 70·3; H, 10·9%). A semicarbazone could not be prepared under the usual conditions.

[6] Cope, Hofmann, Wyckoff, and Hardenbergh, *J. Amer. Chem. Soc.*, 1941, **63**, 3452.
[7] Hope and Sheldon, *J.*, 1922, **121**, 2223; Lapworth and McRea, *ibid.*, p. 2752.
[8] *Org. Synth.*, 1947, **27**, 24; Smith and Roualt, *J. Amer. Chem. Soc.*, 1943, **65**, 634; Knoevenagel and Klages, *Annalen*, 1894, **281**, 94; Rabe, *ibid.*, 1904, **332**, 1.
[9] Longinov, *J. Russ. Phys. Chem. Soc.*, 1915, **47**, 1132.
[10] Wallach, *Annalen*, 1911, **381**, 86.
[11] Verley, *Bull. Soc. chim. France*, 1899, **17**, 176.
[12] Guareschi, *Gazzetta*, 1919, **49**, (i), 124.
[13] Gladstone and Tribe, *J.*, 1879, **35**, 567.

*5-iso**Hexyl-5-methyl**cyclohexane*-1 : 3-*dione*. The preceding ester (36 g.) was refluxed with a solution from sodium (3·2 g.) in absolute ethanol (100 ml.) on the steam-bath for 20 hr. The *diketone* (32·5 g.), on purification from ethyl acetate–light petroleum (b. p. 40—60°), formed colourless prisms, m. p. 77—78° (Found : C, 74·3; H, 10·3. $C_{13}H_{22}O_2$ requires C, 74·3; H, 10·5%).

*3-Chloro-5-iso**hexyl-5-methyl**cyclohex-2-enone*. The above diketone (18 g.), dry chloroform (36 ml.), and phosphorus trichloride (4 ml.) were heated on the steam-bath for 3 hr., and the product was worked up in the usual way, giving the *chloro-ketone* (10 g.), b. p. 165—168°/10 mm. (Found : C, 15·8. $C_{13}H_{21}OCl$ requires Cl, 15·5%). This on hydrogenation gave a liquid which readily yielded a semicarbazone, m. p. 169° (from ethanol) (Found : C, 66·3; H, 10·5%). This showed no depression of m. p. when mixed with the semicarbazone of 3-*iso*hexyl-3-methyl-*cyclo*hexanone described above. The regenerated ketone had b. p. 135—137°/13 mm. (Found : C, 79·4; H, 12·0%).

β-iso*Hexyl-β-methyl-δ-valerolactone* (*lactone of* 3-2′-*hydroxyethyl*-3 : 7-*dimethyloctanoic acid*). The anhydride of β-*iso*hexyl-β-methylglutaric acid (45 g.), in calcium-dried ethanol (183 ml.), was added as rapidly as possible to sodium (37 g.), heated at 80°. The temperature was slowly raised to 135°, and heating continued for 4—5 hr., absolute ethanol (68 ml.) being added from time to time to facilitate dissolution of sodium. The *lactone* (28 g.), isolated in the usual manner, formed an almost colourless liquid, b. p. 146°/8 mm., having a characteristic sweet smell (Found : C, 72·5; H, 11·3. $C_{13}H_{22}O_2$ requires C, 72·7; H, 11·1%).

*Ethyl δ-bromo-β-iso**hexyl-β-methylvalerate* (3-2′-*bromoethyl*-3 : 7-*dimethyloctanoate*). A mixture of the above lactone (27 g.) and phosphorus tribromide (14 ml.) was cooled in a freezing mixture, bromine (8·4 ml.) was introduced gradually with shaking, and the whole left in the cold overnight. It was then heated at 60° for 1 hr., and on cooling, cautiously mixed with absolute ethanol (100 ml.). The *bromo-ester* (38 g.) had a sweet smell and b. p. 142°/5 mm. (Found : Br, 26·5. $C_{14}H_{27}O_2Br$ requires Br, 26·1%).

Triethyl 4-iso*hexyl-4-methylpentane*-1 : 1 : 5-*tricarboxylate* (*diethyl* 4-*ethoxycarbonylmethyl*-4 : 8-*dimethylnonane*-1 : 1-*dicarboxylate*). The bromo-ester (41·2 g.) was heated with ethyl sodiomalonate (ethyl malonate, 24 g.; sodium, 3·2 g.; absolute ethanol, 65 ml.) for 12 hr. The product was diluted with water and extracted with ether; the ethereal solution was washed with water, dried, and distilled, giving an *ester*, b. p. 180°/3 mm. (Found : C, 65·1; H, 9·8. $C_{21}H_{38}O_6$ requires C, 65·3; H, 9·8%).

β-iso*Hexyl-β-methylpimelic acid*. The preceding ester (38 g.) was hydrolysed by boiling with alcoholic potassium hydroxide for 1 hr. The excess of ethanol was removed on the water-bath, and the residual solution acidified and extracted with ether. On removal of the solvent an oil remained which was heated at 180° until evolution of carbon dioxide ceased (3 hr.). On distillation, the required *acid* formed an almost colourless viscous liquid (18 g.), b. p. 213—215°/3 mm. (Found : C, 64·8; H, 10·1. $C_{14}H_{26}O_4$ requires C, 65·1; H, 10·1%). Its *diethyl ester* had b. p. 147—148°/6 mm. (Found : C, 68·5; H, 10·9. $C_{18}H_{34}O_4$ requires C, 68·7; H, 10·8%). The acid (10 g.) was mixed with barium hydroxide (1 g.) and distilled slowly from an air-bath heated to 305—310°. The resulting ketone (5·5 g.), isolated in the usual way, had b. p. 135—136°/12 mm. (Found : C, 79·8; H, 12·3%) (semicarbazone, m. p. and mixed m. p. 169°). The same ketone (11 g.; b. p. 141—142°/15 mm.; semicarbazone, m. p. 169°) was obtained when the substituted pimelic acid (25 g.) was heated with acetic anhydride (65 ml.) for 3 hr. Dieckmann cyclisation of the above diethyl ester (10 g.) with sodium (0·8 g.) in benzene (25 ml.) and hydrolysis of the resultant product with acetic acid (48 ml.) and hydrochloric acid (24 ml.) gave an oil (3·2 g.), b. p. 140—145°/15 mm. (semicarbazone, m. p. 169°).

Ethyl α-cyano-α-(3-iso*hexyl-3-methyl**cyclohexylidene*)*acetate* (I). A mixture of the ketone (37·3 g.), ethyl cyanoacetate (22·5 ml.), ammonium acetate (3·8 g.), acetic acid (10 ml.), and dry benzene (50 ml.) was heated at 130—140° in an oil-bath until no more water [4] was formed (3 hr.). On cooling, water was added, and the benzene solution separated, washed with a little water, dried, and distilled. The unsaturated *cyano-ester* (I) (46 g.) had b. p. 165—167°/5 mm. (Found : C, 74·0; H, 10·1. $C_{18}H_{29}O_2N$ requires C, 74·2; H, 9·9%).

Ethyl α-cyano-α-(1-*cyano*-3-iso*hexyl-3-methyl**cyclohexyl*)*acetate* (II). The above ester (12 g.) was dissolved in ethanol (24 ml.), and a solution of sodium cyanide (4 g.) in water (8 ml.) added. The solution was cooled in ice and treated dropwise with 20% hydrochloric acid (12 ml.). After 1 hr. it was poured into water (100 ml.) containing concentrated hydrochloric acid (4 ml.). The oil which separated was collected in ether, and the ethereal solution washed with water, dried, and distilled. The *dicyano-ester* (II) (11·2 g.) had b. p. 176—178°/3 mm. (Found : C, 71·4; H, 9·6. $C_{19}H_{30}O_2N_2$ requires C, 71·7; H, 9·4%).

Ethyl 1-*ethoxycarbonyl*-3-*isohexyl*-3-*methyl*cyclo*hexylacetate* (as III). The foregoing ester (40 g.), sulphuric acid (100 ml.), acetic acid (70 ml.) and water (30 ml.) were gently refluxed on the sand-bath for 10 hr. On cooling, the solution was saturated with ammonium sulphate and extracted with ether, and on removal of solvent a viscous oil (35 g.) was obtained which was esterified with ethanol (70 ml.), sulphuric acid (7 ml.), and benzene (130 ml.), affording the *diethyl ester* (34 g.), b. p. 178—179°/7 mm. (Found: C, 70·6; H, 10·7. $C_{20}H_{36}O_4$ requires C, 70·5; H, 10·5%). The corresponding acid formed an amorphous mass, and when boiled with acetic anhydride gave the *anhydride*, b. p. 182—183°/5 mm. (Found: C, 72·0; H, 9·6. $C_{14}H_{24}O_3$ requires C, 72·2; H, 9·8%), which slowly crystallised. The *anilic acid* separated from ethanol in prisms, m. p. 177° (Found: C, 73·3; H, 9·2. $C_{22}H_{33}O_3N$ requires C, 73·5; H, 9·2%). The *anil*, obtained on heating the anilic acid, crystallised from aqueous ethanol in needles, m. p. 96° (Found: C, 77·6; H, 9·0. $C_{22}H_{31}O_2N$ requires C, 77·4; H, 9·1%).

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166. *Bis*-2 : 4-*diaminophenyl Sulphone, and a New Synthesis of* 2 : 8-*Diaminophenothiazine* 5 : 5-*Dioxide.*

By HELENA BRADBURY and F. J. SMITH.

IN view of the well-known pharmacological action of bis-*p*-aminophenyl sulphone, it appeared desirable to prepare the closely related tetra-amino-compound from bis-2 : 4-dinitrophenyl sulphone.[1] Tin or stannous chloride with concentrated hydrochloric acid, iron with dilute hydrochloric acid, and titanous sulphate in hot acid solution or in a cold citrate buffer did not give the desired tetra-amine.

However, use of alcoholic stannous chloride, with subsequent addition of concentrated hydrochloric acid, gave an excellent yield—this method was employed by Ullmann and Pasdermajian [2] for the reduction of 2 : 4-dinitrophenyl phenyl sulphone to the diamine.

2 : 8-Diaminophenothiazine 5 : 5-dioxide was obtained in approximately 40% yield from the tetra-amine by prolonged refluxing with zinc chloride and dilute hydrochloric acid. Michels and Amstutz [3] obtained the same substance by a seven-stage synthesis from phenothiazine, but their final yield was very low. They established the orientation by an alternative synthesis, but in our case, the formula appears to be beyond doubt from the method of synthesis and from the fact that the compound resists oxidation with aqueous ferric chloride. 3 : 7-Diaminophenothiazine 5 : 5-dioxide [4] is readily oxidised by aqueous ferric chloride to a coloured quinonoid compound, and an isomer is similarly oxidised; the orientation of the amino-groups in our compound precludes the formation of a quinonoid structure.

Experimental.—Bis-2 : 4-*diaminophenyl sulphone.* Pure crystalline stannous chloride (17 g., 0·12 mole) was dissolved in ethanol (30 ml.) with gentle warming and finely powdered bis-2 : 4-dinitrophenyl sulphone (4·0 g., 0·01 mole) was added with constant swirling at such a rate that the liquid was kept just boiling by the heat of reaction. Hydrochloric acid (*d* 1·19; 30 ml.) was added to the resulting orange-coloured solution and *ca.* 25 ml. of liquid distilled off. The solution was then poured into 10% sodium hydroxide solution (400 ml.). The almost white *tetra-amine*, washed free from inorganic matter, dried at 100°, and crystallised from pure redistilled aniline, formed very pale buff rhombic plates, m. p. 236° (yield, *ca.* 90%) (Found: N, 20·0; S, 11·5. $C_{12}H_{14}O_2N_4S$ requires N, 20·15; S, 11·5%).

From a solution of the substance in hot hydrochloric acid (*d* 1·19), colourless rosettes of a *trihydrochloride* separated slowly on cooling. It was filtered off, washed three times with dry ether, and rapidly dried between absorbent paper (Found: equiv., 130·5. $C_{12}H_{14}O_2N_4S,3HCl$ requires equiv., 129·2). After 4 weeks' exposure to the atmosphere this became a buff-coloured *dihydrochloride* (Found: equiv., 175. $C_{12}H_{14}O_2N_4S,2HCl$ requires equiv., 175·5).

The tetra-amine (3 g.) was added to acetic anhydride (10 ml.) containing one drop of

[1] Bradbury, Smith, and Talman, *J.*, 1953, 1184.
[2] Ullmann and Pasdermajian, *Ber.*, 1901, **34**, 1152.
[3] Michels and Amstutz, *J. Amer. Chem. Soc.*, 1950, **72**, 888.
[4] Ciocca and Canonica, *Boll. Ist. Serioterap. Milanese*, 1944, **23**, 81.

sulphuric acid (*d* 1·84). On gentle warming the substance dissolved to give a brown solution which rapidly became almost solid. Water was added, and after filtration the residue was treated with 2N-sodium hydroxide, in which the tetra-acetyl derivative, but not the tetra-amine, is soluble. The filtered alkaline solution was made just acid with hydrochloric acid (*d* 1·19) and after cooling in ice the *tetra-acetyl derivative* was separated and crystallised from water as needles, m. p. 254—256° (bath preheated at 230°), 268° (slow heating) (Found : N, 12·6; Ac, 38·4. $C_{28}H_{32}O_6N_4S$ requires N, 12·6; Ac, 38·6%).

The tetra-amine (2 g.), 2N-sodium hydroxide (100 ml.), acetone (5 ml.), and benzoyl chloride (2 ml.) gave the *tetrabenzoyl derivative*, m. p. 235° (after shrinking) (from acetic acid) (Found : N, 8·0, 8·0. $C_{48}H_{36}O_6N_4S$ requires N, 8·1%).

2 : 8-*Diaminophenothiazine* 5 : 5-*dioxide*. The tetra-amino-sulphone (5 g.) was heated in a saturated solution of zinc chloride in 2N-hydrochloric acid (20 ml.) at >120° for 72 hr., then poured into 2N-ammonia, and the precipitated impure cyclic base collected and washed with water. It was then boiled with hydrochloric acid (*d* 1·19) and charcoal, then filtered. The insoluble material consisted of the dihydrochloride of 2 : 8-diaminophenothiazine 5 : 5-dioxide, which was dissolved in dilute hydrochloric acid; this solution was boiled with charcoal, filtered, and made alkaline with ammonia, and the liberated diaminophenothiazine dioxide collected, dried, and crystallised from aqueous acetone. It had m. p. 339—342° (decomp.) [2] (Found : N, 16·1, 16·0. Calc. for $C_{12}H_{11}O_2N_3S$: N, 16·1%). From a solution of the above in dilute hydrochloric acid, the dihydrochloride was precipitated in colourless rosettes by the addition of hydrochloric acid (*d* 1·19) (Found : equiv., 167·7. Calc. for $C_{12}H_{11}O_2N_3S,2HCl$: equiv., 167).

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167. *Some Derivatives of* cis-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-*Octahydrophenazine.*

By PATRICIA J. EARLE and MURIEL L. TOMLINSON.

HOPING to obtain an unknown hexahydrophenazine we condensed *o*-phenylenediamine with 2-hydroxy*cyclo*hexanone, but we obtained equimolecular proportions of 1 : 2 : 3 : 4-tetrahydro- and *cis*-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydro-phenazine. These compounds have been described by Clemo and McIlwain,[1, 2] who give reasons for believing that this octahydro-compound, m. p. 147°, is the *cis*-isomer. Mono- and di-acetyl derivatives of this octahydrophenazine have now been prepared, and bromination of them has produced two dibromo-compounds which contain the bromine atoms in different positions, because the 9-acetyldibromo-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine obtained can be acetylated to give a 9 : 10-diacetyl compound different from that obtained by direct bromination of 9 : 10-diacetyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine.

*Experimental.—Condensation of o-phenylenediamine with 2-hydroxy*cyclo*hexanone.* *o*-Phenylenediamine (4·65 g.) and 2-hydroxy*cyclo*hexanone (4·5 g.) were powdered together and heated at 125—145° until evolution of water vapour ceased (10 min.). The mass solidified when cooled, and was recrystallised from ethanol (13 c.c.). *cis*-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-Octahydrophenazine separated and a further quantity was obtained by careful dilution of the filtrate with water (10 c.c.). It was recrystallised again from alcohol and formed plates, m. p. 147° (2·4 g.) (Found : C, 76·9; H, 8·6; N, 14·9. Calc. for $C_{12}H_{16}N_2$: C, 76·6; H, 8·5; N, 14·9%). When water was added to the original mother-liquor crude 1 : 2 : 3 : 4-tetrahydrophenazine separated. It was extracted with light petroleum (b. p. 60—80°) and purified chromatographically on alumina. 1 : 2 : 3 : 4-Tetrahydrophenazine was obtained as waxy prisms, m. p. 93°, raised to 94° on admixture with authentic 1 : 2 : 3 : 4-tetrahydrophenazine, m. p. 95°, made from *o*-phenylenediamine and 1 : 2-dioxo*cyclo*hexane.[1]

9 : 10-*Diacetyl*-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-*octahydrophenazine*. Octahydrophenazine (15 g.) and acetic anhydride (40 c.c.) were boiled (5 min.). Dilution with water afforded 9 : 10-*diacetyl*-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-*octahydrophenazine* (14 g.), which crystallised from alcohol as prisms, m. p. 148° (Found : C, 70·8; H, 7·1. $C_{16}H_{20}O_2N_2$ requires C, 70·6; H, 7·3%). It was hydrolysed to the original octahydrophenazine by boiling hydrochloric acid (½ hr.).

[1] Clemo and McIlwain, *J.*, 1934, 1991.
[2] *Idem*, *J.*, 1936, 259.

9-Acetyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine. (i) Diacetyloctahydrophenazine (5 g.) in alcohol containing potassium hydroxide (5 g.) was boiled for ½ hr. Dilution with water precipitated *9-acetyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine*, which crystallised from alcohol as prisms, m. p. 155° (Found : C, 73·5; H, 7·9. $C_{14}H_{16}ON_2$ requires C, 73·0; H, 7·9%). (ii) Octahydrophenazine (15 g.) was added to acetic anhydride (40 c.c.). It dissolved with evolution of heat, and on cooling 9-acetyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine (8 g.; m. p. 153°) separated. Dilution of the filtrate, and hydrolysis with alcoholic alkali of the mixture of mono- and di-acetyl compounds so produced, afforded more monoacetyloctahydrophenazine (8 g.).

9 : 10-Dibenzoyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine, prepared by the Schotten–Baumann method, crystallised from alcohol as prisms, m. p. 203° (Found : C, 78·8; H, 6·1. $C_{28}H_{24}O_2N_2$ requires C, 78·8; H, 6·0%).

Bromination of 9 : 10-diacetyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine. (i) Bromine (1·79 g.) in acetic acid (20 c.c.) was added to the octahydrophenazine (3 g.) in acetic acid (20 c.c.). A yellow *addition compound* separated at once. It had m. p. 99° (decomp.) and could not be recrystallised. It liberated iodine from potassium iodide in the presence of acid and was itself converted into the original diacetyl compound (Found, by titration : Br, 38·6. $C_{16}H_{20}O_2N_2Br_2$ requires Br, 37·0%). (ii) Diacetyloctahydrophenazine (4·2 g.) was treated with bromine (6·1 g.) in acetic acid (total volume 60 c.c.). The addition compound (8 g.) was collected, and dilution of the filtrate with water gave colourless needles, m. p. 160—170° (2 g.). Recrystallisation from alcohol then afforded a *9 : 10-diacetyldibromo-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine*, m. p. 202—204° (Found : C, 44·9; H, 4·0; N, 7·0. $C_{16}H_{18}O_2N_2Br_2$ requires C, 44·7; H, 4·2; N, 6·5%).

Bromination of 9-acetyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine. Bromine (5·56 g.) in acetic acid (20 c.c.) was slowly stirred into a solution of 9-acetyloctahydrophenazine (4 g.) in acetic acid (40 c.c.). A yellow precipitate separated but redissolved, and addition of water precipitated a solid (6·9 g.). Recrystallisation from alcohol gave a *9-acetyldibromo-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine*, as needles, m. p. 118—120° (Found : C, 43·6; H, 4·4. $C_{14}H_{16}ON_2Br_2$ requires C, 43·3; H, 4·2%). Boiling this dibromo-compound with acetic anhydride containing a trace of sulphuric acid (20 min.) afforded a second *9 : 10-diacetyldibromo-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine*, m. p. 164—165°, different from the above (Found : C, 45·2; H, 4·2%).

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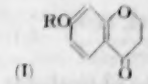
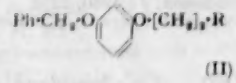
168. *Some Derivatives of Chroman-4-one.*

By RITA A. GREGORY and MURIEL L. TOMLINSON.

7-HYDROXYCHROMAN-4-ONE (I; R = H) is not easily obtained in quantity by either of the methods recorded in the literature for its preparation.[1,2] Requiring this substance as a starting material, we decided to investigate the possibility of preparing it from 7-benzyloxychroman-4-one (I; R = CH_2Ph). *m*-Benzyloxyphenol was condensed with acrylonitrile to give β-3-benzyloxyphenoxypropionitrile (II; R = CN) which was hydrolysed to the corresponding acid (II; R = CO_2H). The most effective method of cyclising the acid (II; R = CO_2H) was by boiling it with phosphoric oxide in benzene,


(I)


(II)

but the yields were not good, and so far it has not proved possible to debenzylate the 7-benzyloxychroman-4-one so produced, neither could hydrogenolysis of β-3-benzyloxyphenoxypropionic acid be effected.

m-Di-2-cyanoethoxybenzene has been converted into 7-2′-carboxyethoxychroman-4-one (I; R = $CH_2{\cdot}CH_2{\cdot}CO_2H$). Simpson, Taylor, and Tomlinson[3] found that some

[1] Pfeiffer, Oberlin, and Konermann, *Ber.*, 1925, **58**, 1947.
[2] Pfeiffer, Breith, and Hoyer, *J. prakt. Chem.*, 1931, **129**, 31.
[3] Simpson, Taylor, and Tomlinson, *J.*, 1951, 2239.

β-2- and -4-aroylphenoxypropionic acids readily lose acrylic acid and give the corresponding phenols, in the presence of aqueous alkali, but the acid (I; R = CH_2·CH_2·CO_2H), which might have been expected to behave similarly, failed to give the chromanone (I; R = H) by this means. Under mild conditions it was unaffected, and more vigorous treatment with alkali caused changes which are probably due to polymerisation.[4]

Experimental.—m-*Benzyloxyphenol.* The method of Klarmann *et al.*[5] was used with the following modification which greatly facilitated purification and gave a 25% yield. The mixture, obtained by boiling benzyl chloride and resorcinol in xylene and pouring on ice, separated into three layers when kept overnight. The lowest layer was dissolved in benzene and washed free from resorcinol with water. After the resulting solution had been dried and evaporated *m*-benzyloxyphenol was purified as described by the original authors.

β-3-*Benzyloxyphenoxypropionitrile.* *m*-Benzyloxyphenol (5 g.), acrylonitrile (10 g.), and a trace of sodium were heated at 95—105° for 30 hr. The resulting solution was poured into sodium hydroxide (10 g.) in water (100 c.c.) and β-3-*benzyloxyphenoxypropionitrile* (6 g.) was obtained as a pink solid. It was recrystallised from benzene–light petroleum (b. p. 80—100°) and formed needles, m. p. 89—90° (Found: C, 75·7; H, 6·1. $C_{16}H_{15}O_2N$ requires C, 75·9; H, 5·9%).

β-3-*Benzyloxyphenoxypropionic acid.* The propionitrile (10 g.) was boiled with hydrochloric acid (100 c.c.) for 3 hr.; a further equal volume of hydrochloric acid was then added, and boiling continued for 2 hr. The solid was collected when cold, and extracted with sodium carbonate solution. Slow acidification of this extract liberated β-3-*benzyloxyphenoxypropionic acid* in a form which could be recrystallised from acetic acid. It separated as prisms, m. p. 166—168°, containing solvent of crystallisation which could be removed by melting (Found: C, 67·5; H, 5·9. $C_{16}H_{16}O_4,\frac{1}{2}C_2H_4O_2$ requires C, 67·5; H, 6·0%).

7-*Benzyloxychroman*-4-*one.* Phosphoric oxide (20 g.) was added during 4 hr. to a solution of pure, dry β-3-benzyloxyphenoxypropionic acid (8 g.) in benzene (200 c.c.) heated under reflux. When the mixture was cold the benzene was decanted and the phosphorus compounds were then decomposed with water, which was extracted with ether. The combined ether–benzene solution was washed with sodium carbonate solution and dried ($MgSO_4$). 7-*Benzyloxychroman*-4-*one* remained when solvents were distilled off, and was recrystallised from light petroleum (b. p. 100—120°), separating as prisms, m. p. 153—155° (Found: C, 75·3; H, 5·5. $C_{16}H_{14}O_3$ requires C, 75·6; H, 5·5%). The original acid (2·7 g.) was recovered. The benzyloxychromanone resisted hydrogenolysis at atmospheric pressure in the presence of palladium–charcoal, palladium-black, and platinum oxide in methanol and ethanol, with or without traces of perchloric acid, and in acetic acid: at 3 atm., only traces of the phenol were formed after hydrogenation for many hours. It was also recovered after boiling in alcohol with Raney nickel, and after long boiling with hydrochloric acid or a mixture of hydrochloric and acetic acids.

7-2′-*Carboxyethoxychroman*-4-*one* (with V. Grenville). *m*-Di-2-cyanoethoxybenzene (5·5 g.) and powdered anhydrous zinc chloride (5·0 g.) were suspended in dry ether (200 c.c.) at 0°, and hydrogen chloride was bubbled in for 4 hr. The product was digested with sodium carbonate solution, starting material (1·8 g.) was removed by filtration, and addition of hydrochloric acid then precipitated 7-2′-*carboxyethoxychroman*-4-*one* (1·6 g.). It crystallised from alcohol as needles, m. p. 173—175° (Found: C, 61·4; H, 5·1. $C_{12}H_{14}O_5$ requires C, 61·0; H, 5·1%).

The Dyson Perrins Laboratory, Oxford. [*Received, October* 3*rd*, 1955.]

[4] Padfield and Tomlinson, *J.*, 1950, 2272.
[5] Klarmann, Gatyas, and Shternov, *J. Amer. Chem. Soc.*, 1931, **53**, 3404.

169. *Triphenylene and 2-Methyltriphenylene.*

By J. W. Barton and J. F. W. McOmie.

An unsuccessful attempt to prepare diphenylene by the action of phenyl-lithium on 2 : 2′-dibromodiphenyl gave triphenylene (8%) and diphenyl. The production of a hydrocarbon from an aryl-lithium has been noted by Gilman and Brannen [1] who obtained small yields of perylene from 1-naphthyl-lithium. It was improbable that the triphenylene was derived solely from the phenyl-lithium, and in order to establish this the action of *p*-tolyl-lithium

[1] Gilman and Brannen, *J. Amer. Chem. Soc.*, 1949, **71**, 657.

on 2 : 2′-dibromodiphenyl was examined. The products of the reaction included 2-methyltriphenylene (5%), but no trimethyltriphenylene, hence these reactions probably proceed *via* a 2-aryl-2′-bromodiphenyl. No reaction occurred between *p*-methoxyphenyl-lithium and 2 : 2′-dibromodiphenyl.

Experimental.—Triphenylene. To a stirred solution of phenyl-lithium, from bromobenzene (16 g.), lithium (1·5 g.), and ether (25 ml.), was added during 15 min. a solution of 2 : 2′-dibromodiphenyl (8 g.) in ether (50 ml.), and the dull red solution was stirred for 4 hr. Next day dilute hydrochloric acid was added and the products were collected in ether. The ethereal extracts were washed with 10% aqueous sodium hydroxide, dried, and distilled, giving fractions: (1) b. p. 50—60°/12 mm., bromobenzene; (2) b. p. 120—130°/12 mm., which after crystallisation from ethanol gave diphenyl (1·3 g.); (3) b. p. 100—150°/0·5 mm., a yellow halogen-containing oil, probably 2-bromodiphenyl (recorded [2] b. p. 296—298°); (4) b. p. 150—190°/0·5 mm., which when crystallised from ethanol gave triphenylene, m. p. and mixed m. p. 194—195° (0·54 g., 8%).

2-Methyltriphenylene. A similar reaction, with *p*-bromotoluene (17·1 g.) instead of bromobenzene, gave fractions: b. p. 60—70°/12 mm., *p*-bromotoluene; b. p. 120—130°/12 mm., 4 : 4′-dimethyldiphenyl (1·0 g.); b. p. 145—155°/12 mm., 4 : 4′-dimethyldiphenyl (trace) and a halogen-containing yellow oil; and a residue which yielded the picrate of 2-methyltriphenylene. This derivative was twice crystallised from ethanol, giving yellow needles, m. p. 191—192° (0·65 g., 5%) (recorded [3] m. p. 192·4—193°). A portion of the picrate in ethanol was passed through an alumina column, and the regenerated hydrocarbon sublimed at 130—140°/0·5 mm. (bath-temperature). After crystallisation from ethanol the 2-methyltriphenylene had m. p. 102—103° (recorded [3] m. p. 102·6—103·6°).

THE UNIVERSITY, BRISTOL. [*Received, October 17th*, 1955.]

[2] Schultze, *Annalen*, 1881, **207**, 353.
[3] Fieser and Joshel, *J. Amer. Chem. Soc.*, 1939, **61**, 2960.

170. αα-Dipropylsuccinic Acid.

By B. J. P. ALLES, (the late) A. KANDIAH, and M. U. S. SULTANBAWA.

IN connection with a study of the formation and stability of β-lactones,[1] αα-dipropylsuccinic acid was required. It has been synthesised according to Lapworth and McRae's method [2] by addition of potassium cyanide to ethyl α-cyano-ββ-dipropylacrylate and hydrolysis of the product with concentrated hydrochloric acid. Attempts to introduce a bromine atom in the α′-position failed (see ref. 1).

Experimental.—Ethyl α-cyano-ββ-dipropylacrylate. This was prepared according to the method of Cope, Hofmann, Wyckoff, and Hardenberg,[3] and had b. p. 132—134°/8—9 mm., n_D^{20} 1·4660.

αα-Dipropylsuccinic acid. A mixture of potassium cyanide (30 g.) in water (70 c.c.) and ethyl α-cyano-ββ-dipropylacrylate (40 g.) in rectified spirits (200 c.c.) was set aside at *ca.* 30° for 8 days. The alcohol was removed under reduced pressure and the residue treated with concentrated hydrochloric acid (60 c.c.), diluted with water, and extracted with ether. The oil left on removal of the ether was refluxed with concentrated hydrochloric acid for 72 hr., the solution then cooled, and the semi-solid mass filtered. *αα-Dipropylsuccinic acid* crystallised from dilute hydrochloric acid as cubes (25 g.), m. p. 86—87° (Found: C, 59·2; H, 8·9%; equiv., 101·2, 101·3. $C_{10}H_{18}O_4$ requires C, 59·4; H, 8·7%; equiv., 101).

αα-Dipropylsuccinic anhydride. The acid (10 g.) was refluxed with acetic anhydride (20 c.c.) for 4 hr. The anhydride (9 g.) distilled at 145—147°/14—15 mm. It was converted into the *anilic acid*, prismatic rods, m. p. 124·5°, from aqueous acetone (Found: C, 69·5; H, 8·5. $C_{16}H_{23}O_3N$ requires C, 69·3; H, 8·4%).

UNIVERSITY OF CEYLON, COLOMBO 3. [*Received, October 31st*, 1955.]

[1] Kandiah, *J.*, 1932, 1215; cf. Bains and Thorpe, *J.*, 1923, **123**, 2742.
[2] Lapworth and McRae, *J.*, 1922, **121**, 2754; cf. Cragoe, Robb, and Sprague, *J. Org. Chem.*, 1950, **15**, 380.
[3] Cope, Hofmann, Wyckoff, and Hardenberg, *J. Amer. Chem. Soc.*, 1941, **63**, 3452.

OBITUARY NOTICES.

ROBERT HENRY ADERS PLIMMER.

1877—1955.

ROBERT HENRY ADERS PLIMMER, who died on June 18th at the age of 78, was the eldest son of Alfred Aders of Manchester. He was educated at Dulwich College and University College, London, graduating B.Sc. in 1899; he then went to Geneva where, under the direction of Professor Carl Graebe he worked on a problem connected with the constitution of euxanthic acid, the yellow substance obtained from the urine of cows fed on mango-leaves and better known as piuri or Indian yellow; to this extent the research had a remote connection with the subject later to become known as biochemistry—a fortuitous example of coming events' casting their shadows before. Actually Aders, as he was then known, had received much encouragement from his stepfather H. G. Plimmer, F.R.S., the Professor of Bacteriology at St. Mary's Hospital, to devote his chemical knowledge and training to physiology and pathology. With this idea in mind he went to Berlin University, where he became a student under Professor Emil Fischer who set him to investigate the products of hydrolysis of gelatine by the, at that time, new technique of separating amino-acids by the fractional distillation of their ethyl esters, under reduced pressure, a method which in the light of modern methods of paper chromatography is only of historic interest. The results of this research were published in the *Annalen* under the joint names of Fischer, Levene, and Aders; it was not until a little time after this that Plimmer adopted his stepfather's name. The experience gained under Fischer was no doubt the inspiration for writing the two monographs on the analysis of proteins some time later. On his return to London, Plimmer was awarded the D.Sc. of London University for a thesis on proteins. His first appointment was to a Grocers' Company research studentship at the Lister Institute; this he held for two years before joining the staff of the Physiology Department of University College under Professors Starling and Bayliss. Starting as an assistant in 1904 he was made Assistant Professor of Physiological Chemistry in 1907 and Reader from 1912 until 1919. During the first World War he was working at the R.A. Medical College on the energy value of foods, which involved a large amount of accurate analytical work the results of which were published by H.M. Stationery Office in 1921. This must in some ways have been a labour after his own heart since all his life he manifested a strong liking for the analytical side of chemistry, his earlier independently published papers being concerned with the quantitative determination of cyanide in presence of chloride and on the phosphate content of phytin. In 1919 Plimmer was appointed head of the Rowett Research Institute, Aberdeen, which had been founded by an old schoolfellow of his whom he got to know at Dulwich College. Here again he had an opportunity for indulging in his liking for analytical work, in assaying the biological value and vitamin content of food stuffs; his interest in vitamins had previously developed while at University College and resulted in the joint publication with his wife, a student of his, of a small book entitled "Food, Health, and Vitamins" which ran into 9 editions. Another most successful publication was the well-known "Organic and Biochemistry" which became the almost universally accepted textbook for 2nd M.B. students and others. From 1922 until 1943 Plimmer held the Professorship of Chemistry at St. Thomas's Hospital Medical School where he was a most successful teacher of inorganic, organic, and biochemistry as well as toxicology. During this time he continued his researches on protein analysis, begun at Aberdeen; on his retirement in 1944 he was made Emeritus Professor. In the same year he was invited to join the Staff of the Postgraduate Medical School of London where he undertook the supervision of the analyses of pathological material. As far back as 1908 Plimmer was appointed co-editor with Professor Sir Frederick Gowland Hopkins, F.R.S., of the well-known "Monographs in Biochemistry." In January, 1911, he and J. A. Gardner called a meeting of biochemists to form a Biochemical Club which later became the Biochemical Society; some years later he wrote the history of the Society for the period of 1911—1949 which was published as a special number of the *Biochemical Journal*; his connection with the foundation of the Society and subsequent development of Biochemistry in this country forms perhaps his best memorial. Plimmer had very strong views on most subjects, a fact which, combined with a somewhat brusque manner, was not conducive to an easy approach and tended somewhat to overshadow his fundamentally generous nature and may have stood in his way of attaining some of the higher scientific honours which were his due.

P. HAAS.

WALTER WILLIAM REED.

1885—1955.

Mr. W. W. Reed was born in Essex and educated at Brentwood Grammar School, passing from there to the University College of North Wales, Bangor. He was awarded a First Class Honours Degree in Chemistry in 1906 and an M.Sc. in 1908. In the same year he took the examination of the Associateship of the Institute of Chemistry, as it was then called, specialising in Organic Chemistry. Three years later he converted this Associateship by examination into the Fellowship of the Institute. On leaving Bangor Mr. Reed joined the staff of the Chemistry Department of the Technical College in Huddersfield where he remained until returning to his native East Anglia to become a Lecturer in Chemistry at the Technical College, Norwich. He stayed at Norwich for the rest of his teaching life, until 1950, being Head of the Science Department and Vice-Principal of the College at the time of his retirement.

Outside the Norwich City College and Art School, Mr. Reed devoted his time to church work and the Church Lads' Brigade. For fourteen years he was People's Warden for the Church of St. Michael at Plea, and since 1912 he had been closely associated with the Church Lads' Brigade.

R. Jones.

SIGMUND OTTO ROSENHEIM.

1871—1955.

Otto Rosenheim's death on May 7th at the age of 84 removes one of the Senior Fellows of the Chemical Society, elected to the Society on May 7th, 1896, and a notable biochemist of uncommon versatility. Rosenheim was born at Würzburg in Germany on November 29th, 1871. In July, 1910, he married Mary Christine Tebb, a Bathurst Student of Girton College and daughter of William Tebb of Rede Hall, Burstow.

Rosenheim took his Ph.D. degree at Würzburg, working under Tafel in Emil Fischer's laboratory. He spent part of the course in Bonn and returned to Würzburg to complete his degree. The subject of his thesis was the oxidation of 6-hydroxyquinoline, and his examiner was Hantzsch who had just succeeded Fischer. After some months of military service he went to Geneva to work with Graebe and there he met Liebermann, Pictet, and Kehrmann. The outlook for one of his persuasion in Germany was not rosy, so Rosenheim decided to make his domicile in England. He therefore wrote to W. H. Perkin at Manchester and Perkin facilitated his entry for research in chemistry at Manchester University in 1895.

In 1896 Rosenheim joined Philip Schidrowitz in practice as Analytical and Consulting Chemists at a laboratory in Chancery Lane, London. Dr. Schidrowitz writes of Rosenheim at that time as a modest and pleasant young man, especially interested in work of a scientific character and in particular in biological chemistry. During their association Rosenheim and Schidrowitz published original observations on a variety of subjects including the optical activity of gallotannic acid, compounds of piperidine with phenols, Fehling's solution, and analyses of modern " dry " champagne.

In 1901 Rosenheim was appointed Research Student of Pharmacological Chemistry in F. W. Tunnicliffe's Department of Materia Medica and Pharmacology at King's College in the Strand. In doing this he was welding an association which had already begun during his practice as consulting chemist. The products of their renewed association were publications on the volumetric estimation of uric acid, the use of piperidine as a uric acid solvent, the influence of borates and of formaldehyde on the metabolism of children, the influence of selenium on certain tests for arsenic, and selenium compounds as factors in a beer-poisoning epidemic. It was at this point that Rosenheim noticed the decomposition of selenium and tellurium compounds by moulds, observations which have been much amplified in recent times by the work of Challenger.

In the autumn of 1904 Rosenheim was appointed Lecturer in Chemical Physiology in Halliburton's Department of Physiology at King's College. Here he collaborated with F. S. Locke in a classical investigation on the effect of certain sugars and of calcium and potassium ions in the perfusion fluid on an isolated mammalian heart. Then followed an investigation into reliable tests for the detection of choline in body fluids. He used the polarising microscope

for differentiating choline platinichloride from inorganic platinichlorides and this instrument was never out of reach throughout his career of research. There then followed a prolonged investigation into brain chemistry. In 1906 he evolved a practical method for preparing cholesterol from brain by mixing minced brain with plaster of paris and sand and extracting the cholesterol at room temperature with acetone; under these conditions the phosphatides were insoluble. In the following year in collaboration with Mary Christine Tebb who was gaining research experience in Halliburton's department, they showed that Liebreich's protagon, a crystalline material obtained by extracting brain with certain solvents, was a mixture, a view diametrically opposed to that of Liebreich, Gamgee, Blankenhorn, and Cramer, but in conformity with Thudichum's classical work on the chemistry of the brain. Rosenheim and Miss Tebb resolved protagon by gentle extraction with suitable solvents into two crystalline substances, phrenosin and kerasin, free from phosphorus, and a residue of sphingomyelin containing phosphorus. The separation of phrenosin and kerasin in a state of complete purity is difficult but Rosenheim's introduction of the selenite plate test in conjunction with the polarising microscope greatly facilitated it. A number of communications on the galactosides of the brain culminated in 1916 in a paper in which constitutions for these two substances were advanced very similar to those accepted today.

In the first decade of this century the subject of pressor bases was much to the fore. Dixon and Tayler believed that the placenta had a normal secretion of a pressor substance, but Rosenheim showed clearly in 1909 that if there was no putrefaction the pressor effect was absent. Incidentally, tyramine was identified by Rosenheim as a product of putrefaction.

In 1915 the title of Reader in Biochemistry was conferred on Rosenheim but in 1920 he resigned his Readership to devote all his time to research.

After a few years of quasi-retirement, Rosenheim and his wife came, in the autumn of 1923, to the Medical Research Council's laboratories at Hampstead with the problem of spermine. They had already worked out a method for preparing the often elusive spermine phosphate crystals first observed in 1678 by Leeuwenhoek, and in collaboration with Dudley and later with Starling they isolated spermine in quantity from pancreas, discovered a new and related base spermidine, determined their constitutions, and finally synthesised both bases.

Rosenheim was deeply interested in vitamin chemistry. In 1908 and 1910 he had worked on rice and the beri-beri problem with Kajima, but in later years the fat-soluble vitamins riveted his attention. With Drummond in 1920 he discussed the possible relation between the lipochrome pigments and the fat-soluble accessory food factors and in 1925 they showed that the well-known colour reaction of cod liver oil with sulphuric acid could be replaced by one using arsenic trichloride. The blue colour produced had a greater permanence, and its intensity was approximately proportional to the content of vitamin A. This in itself was a notable advance; later, results of industrial importance arose from the observation by Rosenheim and Webster, based on colorimetric and feeding tests, that the amounts of vitamin A in liver fats of other species such as salmon and halibut were often 100 times as much as in cod-liver oil.

Rosenheim then turned his attention to vitamin D. With Drummond and Coward he had in 1925 found that the precursor of the antirachitic substance found in foodstuffs on irradiation with ultraviolet light was contained in the sterol fraction. Webster had worked on this problem and had devised a reliable technique for testing antirachitic substances on rats. Rosenheim and Webster joined forces and soon found that dihydrocholesterol could not be activated and that, if cholesterol was irradiated and unchanged cholesterol removed by digitonin, the residue yielded an intensely active antirachitic preparation. On testing many other sterols they found that ergosterol and its acetate were almost the sole substances which could be activated and that ergosterol was in fact provitamin A. The way was thus clear for work on a larger scale, undertaken by Bourdillon, Callow, Webster, and their collaborators, which resulted in 1931 in the isolation and characterisation of vitamin D for which Dale proposed the now accepted name of calciferol.

The constitution of the sterols and bile acids then assumed an added importance. Chemists were familiar with the structures adduced for cholesterol and the bile acids by Windaus and Wieland and were tacitly critical of the blocked quaternary carbon atom in these structures. When the paper by Diels and Gädke appeared in 1927 on the production of chrysene from cholesterol by hot palladised charcoal I drew Rosenheim's attention to it with the comment that I was sure it would revolutionize the structure of cholesterol. To our surprise months passed by without Diels's observation being taken up as of constitutional importance and Rosenheim attributed this to the reverence held for the German masters, Windaus and Wieland, in Germany. In the meantime ergosterol chemistry was being intensively studied by Windaus and Heilbron,

and the numerous ready movements of double bonds in this substance convinced Rosenheim and myself that the blocked quaternary carbon atom formula would have to go. Our opinion received further support from the physical side, for early in 1932 Bernal found, on *X*-ray examination of various sterol crystals, that the dimensions of the cells required a long molecule and were difficult to reconcile with the accepted formulæ. Rosenheim pondered deeply over Bernal's findings and kept harping on them to me. When Bernal's second Note appeared, reaffirming his earlier view, Rosenheim anxiously sought my opinion and on the spur of the moment I said to him, " Why don't you take ring II in the Windaus–Wieland structures and put it on the other side of ring I so as to produce a potential chrysene structure ? " Rosenheim took the problem home and next morning came to me and said excitedly " It fits, it fits." My comment was that any new structure was bound to fit some of the facts of degradation; when however we found that Windaus's degradation of ring I led on our formulation to a five-membered ring ketone and not to the four-membered ring which puzzled Windaus we felt we were on the right lines. After further study we were fortunate in arriving at the complete structure of cholesterol and the ring system of the bile acids now accepted universally.

The new formulae effected a revolution in the chemistry of the sterols, the many bile acids, the heart poisons, the sex hormones, and the constituents of the adrenal glands, and for 23 years have formed the basis of countless original communications.

Rosenheim had for many years been puzzled by the nature of Lifschütz's resinous " oxycholesterol " obtained by debrominating cholesterol dibromide with sodium acetate. The blue colour it gave with sterol reagents fascinated Rosenheim. It so happened that from 1933 to 1943 Rosenheim and his collaborators Callow, Starling, Stiller, and Petrow studied the action of selenium dioxide on sterols and problems connected with the known diols and triols derived from cholesterol. Rosenheim and Starling by the action of selenium dioxide on cholesterol esters obtained a *trans*-cholest-5-ene-3 : 4-diol which gave a blue colour with sterol reagents and was very sparingly soluble in organic solvents. The latter property enabled the authors to show that this *trans*-diol was a constituent of Lifschütz's " oxycholesterol."

Rosenheim was equally at home in problems of nutrition and in metabolic studies. With Webster in 1943 and later he made many highly intriguing observations on the metabolism of cholesterol and allied substances in rats.

In the laboratory Rosenheim was an invaluable colleague. He had a phenomenal memory and was a mine of accurate information. He was philosophic, contemplative, and placid; he was sagacious, cautious, and wise, and his opinion was frequently sought by his many colleagues in the Institute and willingly given. He was a born investigator, he was meticulous and methodical, and he had an unusually pronounced flair for colour reactions. For many years he was a much valued member of the Accessory Food Factors Committee of the Medical Research Council. He was a Fellow of the Linnean Society, and his chief hobbies were rock-gardening and photography. He was elected into Fellowship of the Royal Society in 1927.

HAROLD KING.

GWYN WILLIAMS.

1904—1955.

GWYN WILLIAMS, born on 27th November, 1904, at Willesden Green, was the only child of the late W. J. Williams, J.P., of Cae Ffynnon, Llangystennin, Llandudno Junction, North Wales. His father, after a period of work with the Civil Service, was for many years Secretary of Kodak Ltd.

Williams was educated at University College School and at the University College of North Wales, Bangor, where he graduated with first-class honours in 1924. He remained as a post-graduate student with a maintenance grant from the Department of Scientific and Industrial Research, working under Professor K. J. P. Orton, F.R.S., and Dr. F. G. Soper. In 1927, after taking his Ph.D., he went to Cambridge where he held a Strathcona research studentship at St. John's College for two years and for a further two years a Fellowship of the University of Wales. He graduated Ph.D (Cantab.) in 1931, and for the next five years he worked in the Laboratory of Colloid Science in Cambridge. During 1936 and 1937, and again for a short

period in 1939, he was a guest research worker in the research laboratory of the Eastman Kodak Co., Rochester, New York.

It was not until the Autumn of 1939, at the age of 34, that Williams took up academic teaching as assistant lecturer at King's College, London. The college was evacuated to Bristol from 1939 to 1943 during which time he succeeded Dr. E. W. McClelland as lecturer in organic chemistry and was awarded the D.Sc. degree of the University of Wales.

In 1946 he was appointed to the Chair of Chemistry at Royal Holloway College, University of London, which fell vacant on the retirement of Professor T. S. Moore. The department flourished under his guidance and became an active centre of research. At first Williams carried a heavy load of teaching in a department that was understaffed and inadequately housed; he resisted the temptation to have temporary additional buildings erected and by 1951 a substantial permanent new building was completed which sufficed for all the needs of the department, the staff of which had been increased.

From the time of his first research under Orton, Williams studied the kinetics and mechanism of chemical reactions. He began with Orton's chloramine problem. The *N*-chlorination and *C*-chlorination of acetanilides were shown to be simultaneous side-reactions, and the work was extended to other substituted acetanilides and benzylacetamides and also to anilides in which the acyl group was widely varied. The results were interpreted in terms of the opposed polar effects of substituents although in some instances they were complex. At Bangor he also determined the basic strength of some chloro- and nitro-anilines by the partition method.

At Cambridge he investigated the reactions of bromine with ethylene and vinyl bromide which were known to take place only on polar surfaces. Both reactions had negative temperature coefficients and complicated kinetics, pointing to a process involving a complex formed on the wall of the reaction vessel. At a Faraday Society discussion he contributed a valuable review of the mechanism and kinetics of additions to olefins.

During this period Williams also made, with Dr. A. S. C. Lawrence, a careful kinetic study of the thermal decomposition of benzylidene azine and ω-azotoluene, the reactions being homogeneous, with activation energies of 53 and 35 kcal. $mole^{-1}$, showing the difference in ease of rupture of the C=N and C–N bonds.

In the Kodak research laboratories, Williams began an investigation of the polymerisation of styrene in carbon tetrachloride under the catalytic influence of pure stannic chloride, which was continued in England and published in a series of papers the last of which appeared in 1952.

The polymer formed was shown to have a molecular weight of 1200—3000; increased initial concentration of styrene raised both the rate and the degree of polymerisation. The presence of hydrogen chloride (whether added or arising from the presence of water) caused a complete arrest of this process, and induced a new reaction yielding 1-phenylethyl chloride and short-chain polymers of multiplicity 2—5 the structures of which were demonstrated.

The activation energy of the main polymerisation was about 3 kcal. $mole^{-1}$, and the kinetic results indicated a chain reaction starting from an activated trimer. The short-chain reaction on the other hand had an activation energy of 9·4 kcal. $mole^{-1}$; its mechanism was also formulated by Williams.

During the war years at Bristol several members of the King's College staff undertook for for the Ministry of Supply, at Professor W. E. Garner's suggestion, a laboratory study of the nitration of dinitrotoluene designed to throw light on the process of manufacture of trinitrotoluene. Rates of nitration were found to be proportional to the molar excess of sulphuric acid over water present. Williams took a prominent part in this work and it was largely owing to his enthusiasm that it was extended to a more academic study of the kinetics of nitration of dinitrotoluene in homogeneous sulphuric acid solution. Accurate measurements were made at temperatures from 60° to 120° and in acids from 87% sulphuric acid to strong oleum. The effects of addition of nitrous acid and of bisulphates were examined. With varying concentrations of sulphuric acid the rate of nitration had a maximum value at 92% sulphuric acid. This maximum has, however, no significance for the two-phase manufacturing process where the proportions of reagents are very different.

About 1941—1943 the nature of the nitrating agent was also considered. Solutions of nitric acid in oleum or sulphuric acid were electrolysed and movement of the nitric acid away from the anode was demonstrated. As a result of these and other experiments and of a critical re-examination of a wide range of chemical and physical data a convincing case was made out for the view that the active nitrating agent was the nitronium ion formed by the reaction :

$$HNO_3 + 2H_2SO_4 \longrightarrow NO_2^+ + H_3O^+ + 2HSO_4^-$$

Although an ion NO_2^+ had been suggested earlier by Euler and by Walden a detailed demonstration based on a large body of evidence had not hitherto been provided. The same view was arrived at independently by Westheimer and Kharasch in the U.S.A. who showed that the dependence of rate of nitration on sulphuric acid concentration was closely parallel to the behaviour of trinitrotriphenylmethanol as an indicator in the same acid, ionizing thus:

$$Ar_3C{\cdot}OH + 2H_2SO_4 \longrightarrow Ar_3C^+ + H_3O^+ + 2HSO_4^-.$$

During the same period Ingold and Hughes also came to a similar conclusion as a result of studies of nitration in such organic solvents as nitromethane and acetic acid.

The kinetic results on the nitration of dinitrotoluene had been interpreted on the hypothesis that proton uptake by the medium was a rate-determining factor in the process. This, however, was disproved in 1949 when Melander showed that such nitrations were insensitive to the substitution of tritium for protium at the seat of the attack on the nucleus. As these experiments were made under different conditions Williams himself tested the point by velocity measurements with pentadeuteronitrobenzene and verified that its rate of nitration was the same as that of nitrobenzene within the limits of experimental error.

In order to avoid the complication of the presence of nitrous acid formed by a simultaneous oxidation in the nitration of dinitrotoluene Williams extended the work, and measurements were made on the nitration of nitrobenzene, *p*-chloronitrobenzene, and of trimethyl-*p*-tolylammonium and trimethylphenylammonium salts in which oxidation did not interfere. Details of the first two of these have not yet been published.

The maximum rate of nitration of dinitrotoluene at about 90% sulphuric acid had received a plausible explanation by the hypothesis that proton uptake was rate determining, but this had been shown to be incorrect. An alternative possibility had been considered at an early stage namely that nitration in the most concentrated acids might be retarded as a result of increased salt formation between the substance nitrated and the sulphuric acid of the medium. But, as Williams showed, the rates of nitration of nitrobenzene, *p*-chloronitrobenzene, and the trimethylphenylammonium ion were all at a maximum in about 90% sulphuric acid and salt-formation could not be supposed to account for this in the latter instance since further proton uptake by the ammonium ion was not credible. No simple explanation of the maximum was therefore apparent.

Another question examined was the possibility that the nitric acidium ion $H_2NO_3^+$ or molecular nitric acid might be the main agents in nitrations in the less concentrated acids. In order to test this point Williams made use of Westheimer and Kharasch's method, extending its application to 65—85% sulphuric acid by the use of several other indicators which had measurable ionisation in this region. Ionisations of this type (and of nitric acid to the nitronium ion) were shown to be related to an acidity function J_0:

$$J_0 = -pK_{NO_2{\cdot}OH} - \log([NO_2^+]/[NO_2{\cdot}OH])$$

This function is connected with the Hammett acidity function, H_0, by the relation $J_0 = H_0 + \log a_{H_2O}$ (cf. Gold and Hawes, *J.*, 1951, 2102). The experiments showed that nitration of the trimethyl-*p*-tolylammonium ion is very rapid in acids containing less than 85% of H_2SO_4 and that neither molecular HNO_3 nor the nitric acidium ion could be principally involved, but that the NO_2^+ ion must be formed in this region (although not detected spectroscopically) and that this is in fact the effective nitrating agent.

Another subject investigated for the Ministry of Supply was the reversible *N*-nitration of guanidine in sulphuric acid. The reaction was observed and measured in both directions in acids of concentration 71·5—83% and correlation with the ionisation of indicators again showed that the nitronium ion was the nitrating agent and not molecular nitric acid or the nitric acidium ion.

More recently the esterification of alcohols by nitric acid in presence of sulphuric acid had been studied, a reaction which is in fact an *O*-nitration. The reaction is complicated because the alcohol reacts with both sulphuric and nitric acid, in each case reversibly. A primary alcohol which resisted any other action of the nitric acid was found in dinitrobenzyl alcohol and an examination of the kinetics was begun.

Gwyn Williams had many interests among which were music, literature, mountaineering, and chess. He was bilingual in Welsh and English. He also spoke and read French, German, and Russian, and made abstracts of Russian papers for the Bureau of Abstracts.

His work for European student relief and for refugee scholars in the years before the War revealed his deep human sympathy. He was keenly interested in the work of Coleg Harlech, a residential college for adult education of which he was treasurer. He had in 1935 conducted there an experimental course in the history and methods of science which subsequently became a regular course at Harlech.

Williams served his college as a member of its Council and its finance committee. He was for a number of years Secretary of the Board of Studies in Chemistry of the University and latterly a member of the Senate.

He was an unassuming man, an assiduous and scholarly worker, and a wise and staunch friend. It is a tragedy that his work should have been cut short so abruptly. Having had some symptoms of heart trouble he went into the hospital of St. John and St. Elizabeth, St. John's Wood, for examination, but died suddenly on the 6th April, 1955.

G. M. Bennett.

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